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FEBRUARY 1964

HANDBOOK FOR PREDICTION OF AIR BLAST FOCUSSING

Beauregard Perkins, Jr.
Willis F. Jackson

RDT & E Project No. 1M010501A006

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1240

BPerkins,Jr./WFJackson/idk
Aberdeen Proving Ground, Md.
February 1964

HANDBOOK FOR PREDICTION OF AIR BLAST FOCUSSING

ABSTRACT

This handbook sets forth the procedures and techniques for gathering and evaluating the meteorological data necessary for predicting the focus of air blast from surface or near surface explosions, and it describes simple devices to speed the calculations. In Appendix A, all the graphs necessary for the evaluation are gathered for easy reference. In Appendix B, 87 sets of vertical velocity gradients and the resulting sound ray paths are assembled for rapid determination of focal distance. These should cover most of the conditions to be expected throughout the continental United States.

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LIST OF FIGURES

I. INTRODUCTION

Blast waves are generated whenever explosives are detonated. They generally propagate beyond the area under control, often cause complaints and, at times, claims for damages. This report describes methods and techniques for evaluating conditions that may increase the intensity of the blast waves in specific areas. The techniques can also be used to determine the validity of claims resulting when detonations occur accidentally or without regard to conditions. This report should be helpful to range control officers, demolition officers, safety officers, claims officers, and public relations officers, as well as to personnel engaged in experimental studies involving explosives.

As the air blast formed by a detonation moves past a given position the pressure of the air at this position rises rapidly to a value above the ambient pressure, then decreases more slowly to a value below the ambient pressure, and finally returns to the ambient value. The maximum excess pressure in the wave is referred to as the peak overpressure or simply the pressure of the airblast. The peak overpressure will be taken as the criterion of damage in this discussion.

The blast wave attenuates very rapidly to a sound wave. The laws of sound propagation apply and the terms blast waves and sound waves will be used synonymously in this report. To determine the path of a ray of sound through the atmosphere, the initial direction of the ray from the source and the manner in which the propagation velocity varies with altitude must be known*. If the velocity of sound is uniform throughout the air above the ground surface, the blast wave will move out uniformly in all directions and the sound rays will look like the spokes of a wheel, as shown in Figure 1. If the velocity decreases from the surface upward, all sound rays will be turned upward away from the ground surface, as shown in Figure 2, and the intensity of the sound along the surface will decrease very rapidly. If the velocity increases with altitude the rays will be turned toward the ground, as shown in Figure 3, and the intensity at any point along the surface will be from 3 to 6 times as great as it would be at the same distance in a uniform velocity field.

*For a discussion of the theory of the propagation of sound waves through the atmosphere, see BRL Report No. 1118 and references cited there.

Combinations of decreasing and increasing velocities from the surface up to 12 or 15 thousand feet can cause the wave to be returned to the surface 5, 10, or 15 miles away and the wave front may actually converge, as shown in Figure 4. The convergence increases the intensity of the wave as much as 100 times over that of a wave traveling at uniform velocity.

The velocity of sound in the atmosphere depends on the speed and direction of the wind, the air temperature, and the humidity. The velocity of sound will be increased in a downwind direction and decreased in an upwind direction. Consequently, the effect of the wind will depend on the component of wind in the direction under consideration. Changes in velocity caused by fluctuations in relative humidity are less than the experimental error in the determination of the wind effect, therefore, humidity, can be neglected. Thus, the paths of sound rays through the atmosphere can be calculated if the values of air temperature, wind speed, and wind direction at the ground surface and at frequent intervals of altitude up to about 12,000 feet are known.

With these data, the responsible officer can determine the velocity gradients present in the atmosphere, whether or not a focus of the blast wave may occur, and the intensity of the blast at particular locations. He can then decide when to detonate without damage and thus avoid justifiable complaints. The steps involved in the procedure are:

1. Tabulate temperature, wind speed and wind direction for each elevation from surface up to about 12,000 feet.

2. From a map of the area determine the directions from the location of the explosion to the various areas where annoyance or damage can occur. These are the azimuths of interest.

3. <u>Considering</u> <u>only</u> <u>one</u> <u>azimuth</u> of interest at a time, calculate the angle between the wind direction and the azimuth at each elevation and the wind velocity component along the azimuth.

4. Adjust the velocity of sound for the temperature of the air at each elevation.

5. Calculate the total change in velocity due to both temperature and wind for each elevation.

6. Plot velocity versus altitude and determine vertical velocity gradients in the atmosphere from this graph.

7. Obtain the multiplication factor for the conditions represented on the graph by comparing the graph with the various possible combinations of gradients.

8. Compare the velocity gradients in the graph with the library of 87 cases to observe the location of the focus if one exists.

9. Determine overpressure in the sensitive regions along the azimuth under consideration.

10. Repeat Steps 3 through 9 for other azimuths.

Section II tells how to secure the data required and describes techniques to speed the calculations. Section III delineates the types of gradients to be expected, the resulting ray paths and the resulting increase in intensity, i.e. multiplication factor. Means of determining the distance to the focus is described in Section IV.

The magnitude of airblast pressures that may cause damage and the type of damage to be expected is discussed in Section V.

There are times when it is necessary to destroy ammunition even though the meteorological conditions are unfavorable. In these instances airblast pressures may be reduced by burial of the explosive charge. The reduction of airblast pressures along the surface by burial of the explosive is described in Section VI.

To help the officer evaluate claims, Section VII states "Forty Reasons Why Walls and Ceilings Crack", and gives references to pertinent publications.

Appendices A and B provide a handy reference for the evaluation of the meteorological data required in Steps 7 and 8.

II. DATA AND CALCULATIONS

The necessary data--air temperature, wind speed and wind direction at various altitudes--can be supplied by any meteorological station having Rawinsonde equipment. Data should be taken approximately every 500 feet from the surface up to 5000 feet. Above 5000 feet the intervals should be about 1000 feet. Since the meteorological conditions seldom remain constant for long periods, the data should be gathered within three hours before the detonation. For rapid calculation, data can be assembled as shown in Figure 5.

Azimuths of Interest and Wind Direction

One or more sensitive areas where damage or annoyance may occur will lie within possible range of the blast waves from any given point of detonation. The direction to these areas are the azimuths of interest. If no appreciable wind is blowing either at the surface or aloft, the velocity gradient in the atmosphere will be determined by the air temperature only and the effect on the ray paths will be the same in all directions, i. e. a picture of the ray paths in one direction will be the same as that in any other direction. However, if an appreciable wind is blowing, the velocity of the sound wave is increased in a direction downwind and decreased in a direction upwind. Across wind the change in velocity due to the wind will be negligible. Under such conditions a focus can exist downwind while no focussing conditions may be found in directions upwind or across wind. The effect on the velocity gradient depends on the component of the wind velocity along the azimuth of interest. This statement means that the angle between the wind direction and the azimuth of interest must be noted at each altitude where wind velocity is measured. The product of the cosine of this angle and the wind speed at that altitude is the component affecting the speed of the blast wave along the azimuth. If the angle is less than 90 degrees the direction of the wind component will be toward the sensitive area, i.e. the wind component will be positive. If the angle is between 90 degrees and 180 degrees the direction of the wind component will be toward the source of the blast wave and the wind component will be negative. This calculation must be repeated for each altitude.

When a focus is caused by winds, the focal area will be in a direction toward which the upper winds are blowing and will lie in a region bounded by rays at approximately 30 degrees from the direction of the wind.

Wind Board

The wind component can be determined quickly and conveniently by the use of a wind board, as illustrated in Figure 6. The arm which rotates around the center of the board is graduated in knots on one half and in miles/hour on the other half. The vertical graduations on the board are spaced to read wind component in feet per second. If the wind at a given altitude has been measured as 20 miles/hour in a direction 32 degrees from the azimuth of interest, the portion of the arm graduated in miles/hour is set at the angle of 32 degrees as in Figure 6. The graduation for 20 miles/hour intersects the vertical graduation for 25 feet/sec. on the board. This is the component of wind velocity in the direction of the azimuth of interest.

The elements and dimensions for the construction of the wind board are shown in Figure 7. The arm can be made of plastic approximately 1/4 inch thick with graduations marked on the lower side to reduce parallax. A drawing of the board, using dimensions given in Figure 7, can be mounted on a plastic sheet 1/8 inch thick and covered with thin plastic. A small bolt through the center of the arm and the center of the board will complete the assembly.

Calculations

Since the ray paths are determined only by velocity gradients in the atmosphere, the absolute value of the velocity of sound is of minor importance. The calculations can be greatly simplified by assuming a velocity V_o in still air at zero degrees Centigrade and then adding to this velocity the changes caused by the difference between the ambient temperature and 0 ^{o}C. and the change of velocity due to the wind component along the direction being considered. The velocity of sound increases approximately 2 ft/sec for a rise in temperature of 1 ^{o}C.; therefore the velocity at any altitude (a) is:

$$V_a = V_o + 2(T_a) + \text{wind component},$$

where:

V_a = Velocity at any altitude "a"

V_o = Velocity at temperature 0 ^{o}C

T_a = Air temperature ^{o}C at altitude "a".

Since V_o is common to all velocity values the gradient can be determined by plotting (2 T_a + wind component) versus altitude. This technique simplifies the calculations.

The meteorological data supplied is tabulated in columns 1, 2, 3, and 9 of the data sheet. The investigator may choose one or more directions to explore or he may choose to investigate the direction in which conditions will be the worst, that is, a direction parallel to the upper winds, and then the direction at right angles to the first direction. Let us assume that the directions a, b, and c have been chosen. The calculations proceed as follows:

1. At each altitude multiply the air temperature by 2 and record in Column 14, Figure 5.

2. The wind direction as given by the meteorological stations will be the direction <u>from</u> which the wind is blowing and will be expressed in degrees from true North. But we want the direction <u>to</u> which the wind is blowing. We obtain it

by adding 180 degrees to the recorded value if that value is less than 180 degrees, or subtracting 180 degrees if the recorded value is between 180 degrees and 360 degrees. The value obtained is put in column 4.

3. The angle between the direction to which the wind is blowing and the direction "a", the first azimuth of interest, is equal to the difference between each value in Column 4 and the value "a". These differences are recorded in Column 5.

4. The component of the wind velocity in direction "a" can be read from the wind board described above or can be derived from the product of the wind speed and the cosine of the angle recorded in Column 5 for each elevation. This component is recorded in Column 10.

5. The total change in acoustic velocity due to wind and air temperature is the sum of the values in Columns 10 and 14 at each elevation. This sum is tabulated in Column 15.

6. The values in Column 15 are then plotted versus altitude and the gradients are measured and marked on the graph. If the graph is composed of a great number of small segments it can be simplified by approximating several short segments with one average line. See Appendix B for examples of graphs.

7. Repeat Steps 3 through 6 for directions b and c.

III. RAY PATHS FOR VARIOUS GRADIENTS

The graphs resulting from the preceding calculations may exhibit a zero gradient, a positive gradient, a negative gradient, or a combination of two or more of these gradients. Each graph will have a characteristic pattern of ray-paths determined by the combination of gradients in the atmosphere traversed by the blast wave. The combinations of gradients appearing on the graph therefore determine the intensity at various distances from the source due to convergence or divergence of the wave front. These gradients are discussed in this section.

Zero Gradient

When the gradient is zero the velocity of the sound rays does not change. For this reason all the rays emanating from a source point will radiate outward like the spokes of a wheel as shown in Figure 1. The resulting pressure of a blast wave traveling along the ground surface has been measured under conditions of a zero gradient for various weights of explosive. A pressure versus distance

chart is shown in Figure 8. When the velocity of sound changes with altitude the vertical gradients become either positive or negative. Pressures produced by explosions at various distances when these other gradients exist in the atmosphere can be described as some multiple or fraction of the value shown in the pressure versus distance chart for zero gradient conditions. These multiples are called "multiplication factors" for particular combinations of gradients.

Negative Gradient

When the sound velocity decreases with altitude, all the rays are refracted upward. Except for a little scattered energy, none of the sound is audible at the ground surface beyond a short distance. Thus the multiplication factor for a negative gradient is zero.

Positive Gradient

When the sound velocity increases with altitude, all the rays are refracted toward the ground surface. A ray starting from the surface at any angle of departure with the horizontal follows the arc of a circle until it again meets the surface. The highest point of the path is the midpoint. The horizontal distance between the points of departure and arrival in the horizontal plane is called the range of the ray.

A very common condition is one in which the positive gradient extends from the surface to altitude "a" with a negative gradient extending above the altitude "a". Ray paths for this condition are shown in Figure 4. The ray having an angle of departure that allows it to reach an altitude "a" and return to the ground surface will be the limiting ray. Rays with an angle of departure greater than that of the limiting ray will enter the region of the negative gradient and be refracted away from the surface, while rays with an angle of departure less than that of the limiting ray will rise to an altitude less than "a" and return to the surface at a horizontal distance less than that reached by the limiting ray. That is, the limiting ray has the maximum range under this particular condition. Also under this condition the intensity of the sound in the region between the source and the maximum range is greater than that under the conditions of a zero gradient. The increase in intensity will be greater under a strong gradient than under a weak gradient and will be greater close to the source. For practical purposes a single multiplying factor of 5 has been chosen for all gradients normally experienced. Beyond the maximum range the multiplying factor is zero. However, if the sound is incident on a water surface, the energy is reflected

back into the atmosphere and the phenomena is repeated. Under these conditions there is no limiting ray and the multiplying factor remains 5.

The maximum range depends on the magnitude of the positive gradient and the altitude to which it extends. Figure 9 gives the maximum range for various gradients to altitudes up to 5000 feet.

Combination of Zero Gradient and Positive Gradient

When an atmospheric layer having a velocity gradient of zero is adjacent to the ground surface and is overlain by a layer in which the velocity gradient is positive, the ray paths will be similar to those depicted in Figure 10. Some of the rays will converge to a focus. This condition produces the weakest focus with which we are concerned. The multiplying factor for the region of the focus is 10.

Combination of Two Positive Gradients

Conditions sometimes exist when in each of the first two layers just above the surface there is a positive velocity gradient. When the upper gradient is weaker than the lower gradient, the resulting pattern of rays consists of two groups returning to the surface. The intensity of sound along the surface is increased under each bundle of rays. Figure 11 shows this pattern. The multiplying factor for each region is 5, the same as under a single positive gradient. However, when the upper gradient is stronger than the lower gradient, the pattern of ray paths has a definite focus as shown in Figure 12. The multiplying factor for the region of focus is 25. For the regions on either side of the focus the multiplying factor is 5.

Combination of a Negative Gradient and a Positive Gradient

If a negative velocity gradient exists in the layer of atmosphere touching the ground surface and a positive gradient exists in the layer above, the sound rays will be deflected away from the ground surface while being propagated through the lower layer and be deflected in the opposite direction while propagating through the upper layer. If the second layer is sufficiently thick so that the positive gradient can increase the velocity of the sound until it is greater than the velocity at the surface, the sound wave will be refracted back to the ground surface and be converged to a focus as illustrated in Figure 13. Focussing under these conditions is the most severe; the multiplying factor for the region of focus is 100.

The various combinations of gradients to be expected and the appropriate multiplication factors have been summarized in Appendix A for easy reference.

IV. LOCATION OF FOCUS

Identification of the plot of velocity versus altitude made from the meteorological data with one set of conditions described in the preceding section will show if a focus exists and also the multiplication factor. The ray paths for characteristic combinations of gradients have been calculated on the Electronic Ray Tracer analogue computer. These calculations are discussed in the BRL Report No. 1118 and 87 cases are assembled in Appendix B of this handbook for convenient reference. If a case can be found in which the gradients and the altitude limiting the first layer are approximately the same as in the case under consideration, the distance from the source to the focus can be obtained from the picture of the ray paths. The overpressure due to the blast wave in the focus area will depend on the weight of explosive, the distance to the focus, and the multiplication factor for the combination of gradients. The pressure versus distance chart (Figure 8) will give the overpressure along the surface for the particular weight of explosive to be detonated. The product of the pressure at the focal distance and the multiplication factor will equal the overpressure in the focal area.

If on the velocity versus altitude graph being considered, either the magnitude of the gradients or the altitude to which the first gradient extends is between values shown in the cases, appropriate interpolation will provide the distance to the focus. To aid in interpolation, graphs of the combinations of gradients and the distance to the focus for each case have been assembled in Figures 14A to 14I*. These graphs will avoid the necessity of thumbing through the many pages of cases to make a double interpolation. Their use will be demonstrated by two examples.

Example 1. From the surface to 1000 feet the gradient is -.010 ft/sec/ft. From 1000 feet to 3000 feet the gradient is + .014 ft/sec/ft. Above 3000 feet the gradient is negative.

First observe the velocity versus altitude plot to see if the velocity in the second layer increases to a value greater than the value at the surface. If

* Some of these graphs are based on the calculations by the BRL analogue computer but many of them are based on calculations at the Naval Weapons Laboratory, Dahlgren, Virginia, on the digital computer by Dr. H. Lugt in collaboration with Mr. Don Ammerman and V. Philipchuk.

it does not the sound waves will not return to the surface and a focus at the surface cannot exist. For this example, the sound velocity increases to a value greater than the sound velocity at the surface. This is readily determined from case numbers 81 and 82 of Appendix B. The corresponding ray paths indicate that a focus will exist between 32 and 50 kilofeet. A focal distance of 42000ft. is obtained from Figure 14G.

Example 2. From the surface to 3000 feet the gradient -.008 ft/sec/ft. From 3000 feet to 6500 feet the gradient is +.010 feet/sec/ft. Above 6500 feet the gradient is negative.

The velocity versus altitude plot indicates that a focus can exist at the surface.

No graph exists for a 1st gradient of -.008 ft/sec/ft. Figures 14F and 14G provide focal distances for 1st gradients of -.005 ft/sec/ft, and -.010 ft/sec/ft with a 2nd gradient of +.010 ft/sec/ft. It is therefore necessary to determine the focal distance for a 1st gradient of -.005 to 3000 feet with a 2nd gradient of +.010 ft/sec/ft and the focal distance for a 1st gradient of -.010 ft/sec/ft to 3000 feet with a 2nd gradient of +.010 ft/sec/ft and then interpolate between these for the focal distance when the 1st gradient is -.008 ft/sec/ft.

For a 2nd gradient of +.010 ft/sec/ft read on Figure 14F the value of the focal distance midway between the 2000 and 4000 feet altitude lines. This value is 78,000 feet, i.e., the focal distance for the 1st gradient of -.005 to 3000 feet and a 2nd gradient of +.010 is 78,000 feet. Similarly on Figure 14G for a 2nd gradient of +.010 read the focal distance midway between the 2000 and 4000 feet altitude lines. This value is 93,000 feet and is the focal distance for a 1st gradient of -.010 ft/sec/ft extending to 3000 feet with a 2nd gradient of +.010.

Summarizing the above:

1st Gradient (ft/sec/ft)	Extending to Altitude (feet)	2nd Gradient (ft/sec/ft)	Distance (feet)	Interval (feet)
-.005	3000	+.010	78,000	15,000
-.010	3000	+.010	93,000	

The value of the 1st gradient of -.008 is at a point 3/5 of the interval between -.005 and -.010 so that the focal distance for the value of the 1st gradient of -.008 to 3000 feet and a 2nd gradient of +.010 will be 78,000 feet plus 3/5 of 15,000 feet or 87,000 feet.

Let us assume 1000 pounds of TNT is to be detonated. The overpressure due to the exploding of 1000 pounds at a distance of 87,000 feet with a zero velocity gradient in the atmosphere is given by the pressure versus distance curve as .0007 psi. The multiplication factor in the focal area for the combination of a negative gradient and a positive gradient is found in Section III to be 100, therefore the overpressure in the focal area will be 100 times .0007 psi, or .07 psi.

V. DAMAGING AIR BLAST PRESSURES

The damage caused by the overpressure of the blast wave depends on the type of construction, material, and dimensions. Glass panes of average size and thickness vary greatly in their ability to withstand blasts depending on how the panes are mounted. If the pane is cut to fit the frame perfectly and can be mounted without any strain in the glass, an overpressure of about 0.75 psi will generally be required to crack it. However, if the pane is forced into the frame so that it is under constant strain, a blast wave of 0.1 psi can cause the pane to crack.

The cracking of plaster on a wall depends on the flexibility of the wall. A plastered surface attached to a masonry wall will withstand a much higher pressure than a surface supported by a wide wooden panel. In general a well-constructed plastered wall will stand higher overpressures than average window panes.

An overpressure of .03 to .05 psi in a blast wave can cause a loose window sash to slap the window frame and produce a loud noise while no actual damage is being done. In constrast, the quiet settling of one corner of a house can cause damage to walls and windows which is often attributed to blast waves. Similarly the removal of supports in a wall to provide a wide opening and failure to reinstall adequate supporting structure will cause damage to the wall above the opening.

If the evaluation of the meteorological data and the magnitude of the charges to be detonated are such that the overpressure to be expected in the sensitive areas is 0.1 psi or greater, the firing program should be postponed.

CAUTION

When the sound waves are incident on a land surface where shrubs and trees are growing, the wave front will generally be destroyed and the reflected wave can be neglected. However, when the waves are incident on a water surface, the waves are reflected somewhat similar

to light reflected from a mirror. In this case the waves under a single positive gradient would not have a limited range since the reflected waves would be refracted back to the surface and be reflected repeatedly, thus being heard far beyond the maximum range discussed above. When a focus occurs at a water surface the energy rises as though from a new source and will be focussed again at a point twice as far from the source as the first focus. The overpressure at the second focal distance should be calculated using the total distance to the second focus and the same multiplying factor used with the first focus.

VI. REDUCTION OF AIR BLAST PRESSURES BY BURIAL OF EXPLOSIVES

There are times when it is desirable to destroy ammunition in spite of unfavorable meteorological conditions. Airblast due to detonation of explosives can be greatly reduced by burial of the charge. The burial should be in unconsolidated material which would attenuate any seismic vibrations generated by the explosion. However, in burying the charge, precaution must be taken to avoid placing it close to a layer of hard rock on which buildings may be resting, since vibrations generated by the explosion will be transmitted to the buildings and cause annoyance or even damage. The unconsolidated soil should be sufficiently thick to permit burial of the charge deep enough to reduce the airblast to a safe value and still have sufficient soil below the charge to reduce ground vibrations to a safe level. Very large charges require greater separation from the rock layer than small charges, but a little experimentation in the area will establish safe limits of charge size for each situation.

The reduction in the airblast by burial is shown in Figure 15. The graphs refer to any size charge. The horizontal distance from detonation to point of observation and the depth of burial is expressed in scale units of lambda (λ). λ is the distance in feet numerically equal to the cube root of the explosive weight in pounds. The use of the curves will be illustrated in the following example:

It is desired to dispose of 1000 pounds of explosive. A building is 1000 feet from the point of detonation. Can the explosive be detonated in one charge? At what depth should it be buried? The cube root of the charge weight in pounds is 10. That is, the length of λ is 10 feet. The distance to the building is 100λ. The chart (Figure 15) tells us that the overpressure of the blast wave

from a surface explosion at a distance of 100λ is approximately 0.3 psi, which may damage the building. However, if the explosive is buried at a depth of 1λ (10 feet), the airblast pressure at a distance of 100λ will be 0.015 psi and the airblast from the detonation would cause no damage.

VII. INVESTIGATING DAMAGE CLAIMS

With the increase in the number of facilities for experimental work involving explosives, many young men with limited experience in structural damage are being asked to appraise damage claims. Engineering training in structural design or advice from a seasoned engineer will be invaluable, but the following four references will be of great help.

1. The National Board of Fire Underwriters, 85 John Street, New York 38, New York, has prepared a pamphlet entitled "Blasting Claims--A Guide for Adjusters".

2. The United States Department of Interior has issued Bureau of Mines Bulletin No. 442, "Seismic Effects of Quarry Blasting", which gives a general discussion on the vibration of structures and resulting damage.

3. The Department of Interior, Bureau of Mines Report of Investigation No. 5968, "Review of Criteria for Estimating Damage to Residences from Blasting Vibrations" establishes damage criteria for ground transmitted vibrations.

4. The Architect's Small House Service Bureau of the U. S., Inc., Minneapolis, Minnesota, has published a list of forty reasons why walls and ceilings crack. These are reproduced below as copied from the Architect's Handbook.

Forty reasons why walls and ceilings crack are:

1. Building a house on fill.

2. Failure to make the footings wide enough.

3. Failure to carry the footings below the frost line.

4. Width of footings not made proportionate to the loads they carry.

5. The posts in the basement not provided with separate footings.

6. Failure to provide a base raised above the basement flood line for the setting of wooden posts.

7. Not enough cement used in the concrete.

8. Dirty sand or gravel used in the concrete.

9. Failure to protect beams and sills from rotting through dampness.

10. Setting floor joists one end on masonry and the other on wood.

11. Wooden beams used to support masonry over openings.

12. Mortar, plaster, or concrete work allowed to freeze before setting.

13. Braces omitted in wooden walls.

14. Sheathing omitted in wooden walls (Except in "backplastered" construction).

15. Drainage water from roof not carried away from foundations.

16. Floor joists too light.

17. Floor joists not bridged.

18. Supporting posts too small.

19. Cross beams too light.

20. Subflooring omitted.

21. Wooden walls not framed so as to equalize shrinkage.

22. Poor materials used in plaster.

23. Plaster applied too thinly.

24. Lath placed too close together.

25. Lath run behind studs at corners.

26. Metal reinforcement omitted in plaster at corners.

27. Metal lath omitted on wide expenses of ceiling.

28. Metal reinforcement omitted where wooden walls join masonry.

29. Plaster applied directly on masonry at chimney stack.

30. Plaster applied on lath that are too dry.

31. Too much cement in the stucco.

32. Stucco not kept wet until set.

33. Subsoil drainage not carried away from walls.

34. First coat of plaster not properly keyed to backing.

35. Floor joists placed too far apart.

36. Wood beams spanned too long between posts.

37. Failure to use double joists under unsupported partitions.

38. Too few nails used.

39. Rafters too light or too far apart.

40. Failure to erect trusses over wide wooden openings.

Careful perusal of these references will provide explanations for most of the alleged structural damage that will be far more logical than attributing the damage to airblast from explosions.

B. Perkins, Jr.
B. PERKINS, JR.

W Jackson
W. JACKSON

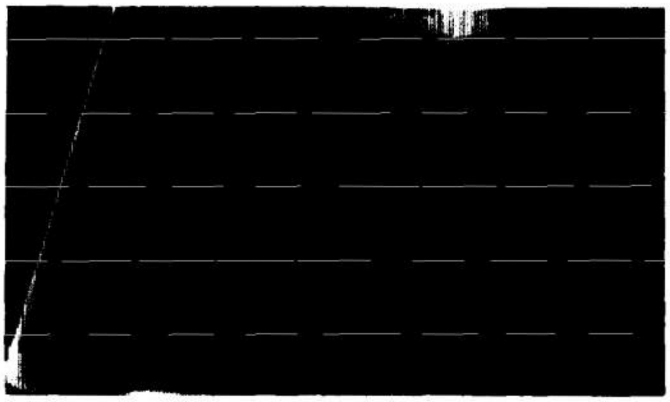


FIG. 1 RAY PATHS IN AIR WHEN VERTICAL VELOCITY GRADIENT IS ZERO.

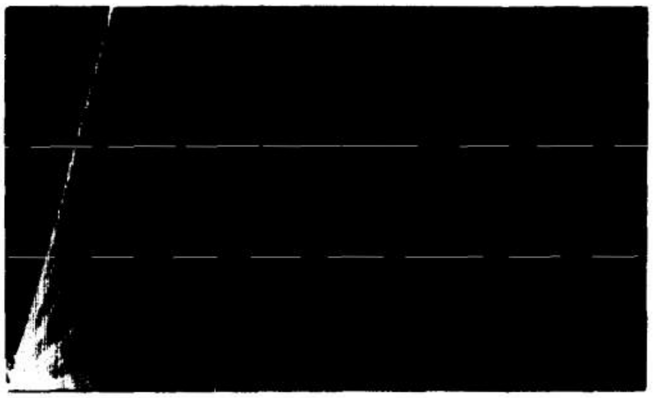


FIG. 2 RAY PATHS IN AIR WHEN VERTICAL VELOCITY GRADIENT IS NEGATIVE.

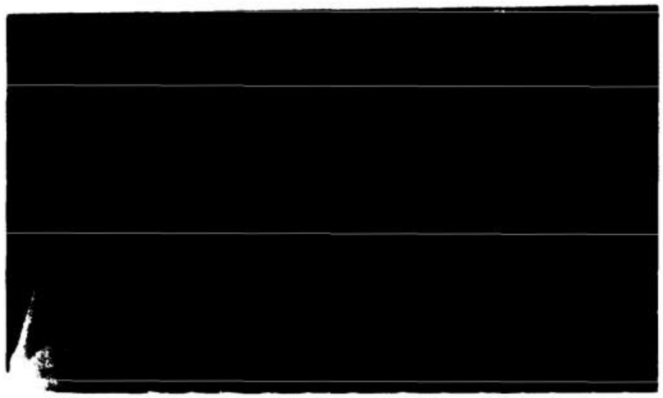


FIG. 3 RAY PATHS IN AIR WHEN VERTICAL VELOCITY GRADIENT IS POSITIVE.

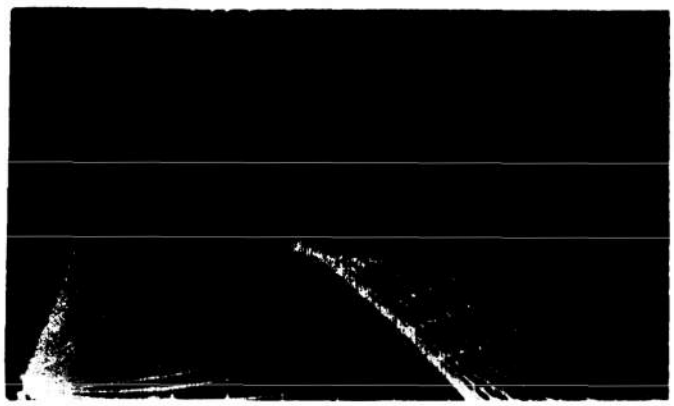


FIG. 4 RAY PATHS IN AIR WHEN VERTICAL VELOCITY GRADIENT IS NEGATIVE IN AIR LAYER CLOSE TO SURFACE AND POSITIVE IN THE LAYER IMMEDIATELY ABOVE.

DATE ________ RELEASE TIME ________ LOCATION ________

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	T	WIND DIRECTION		∢ BETWEEN VALUE IN COL. 4 AND DIRECTION:				WIND VEL.	B				2 T	B + 2 T			
ALT.	TEMP.								COMPONENT WIND VELOCITY (FPS) IN DIRECTION:				ΔV_T	TOTAL CHANGE IN ACCOUSTIC VEL. DUE TO WIND & TEMP. IN DIRECTION:			
(FT.)	(°C)	FROM	TO	____	____	____	____	(MPH)	____	____	____	____	(FPS)	____	____	____	____

FIGURE 5. SAMPLE DATA SHEET

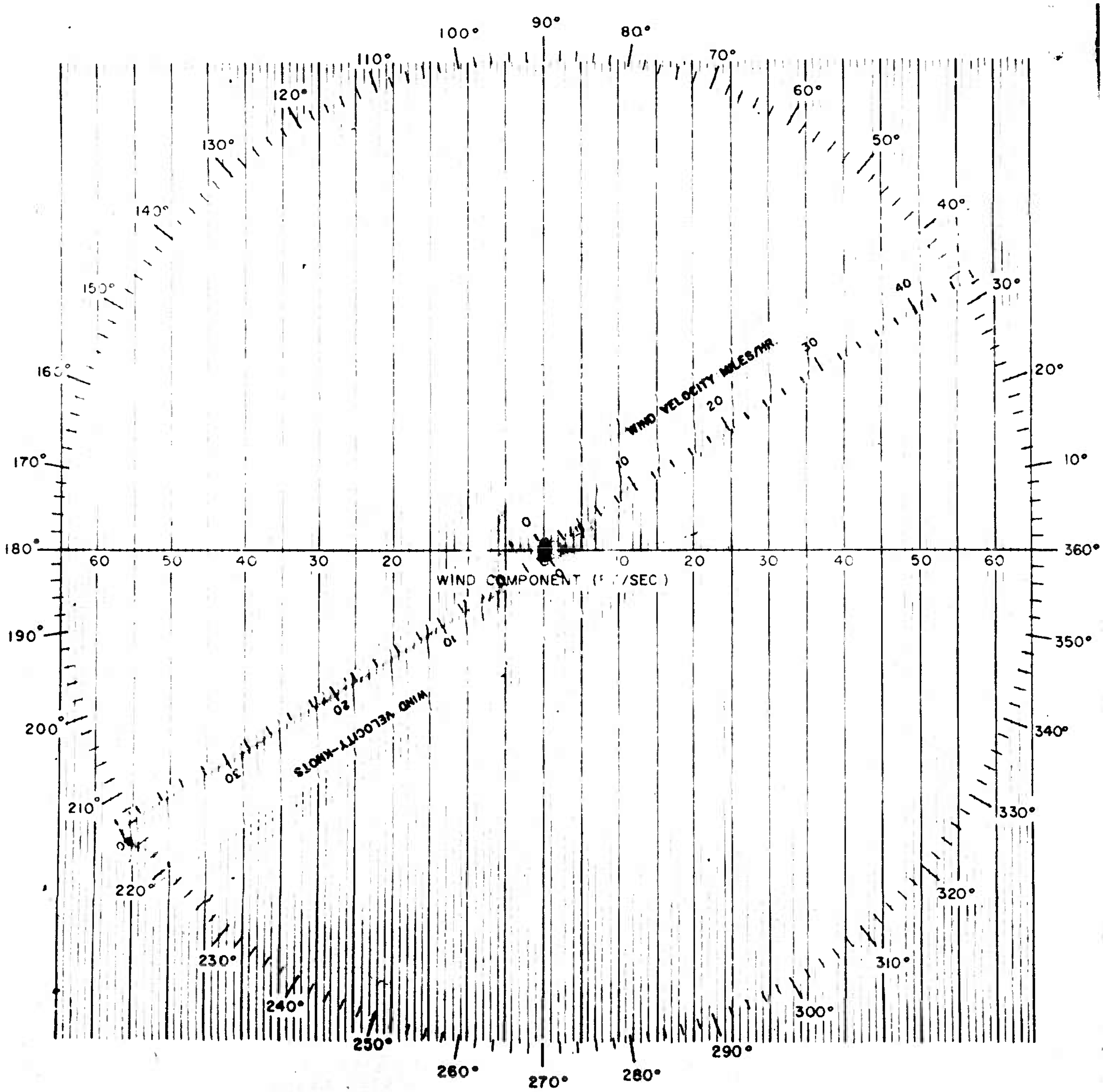


FIG. 6 WIND BOARD FOR CALCULATING WIND COMPONENTS

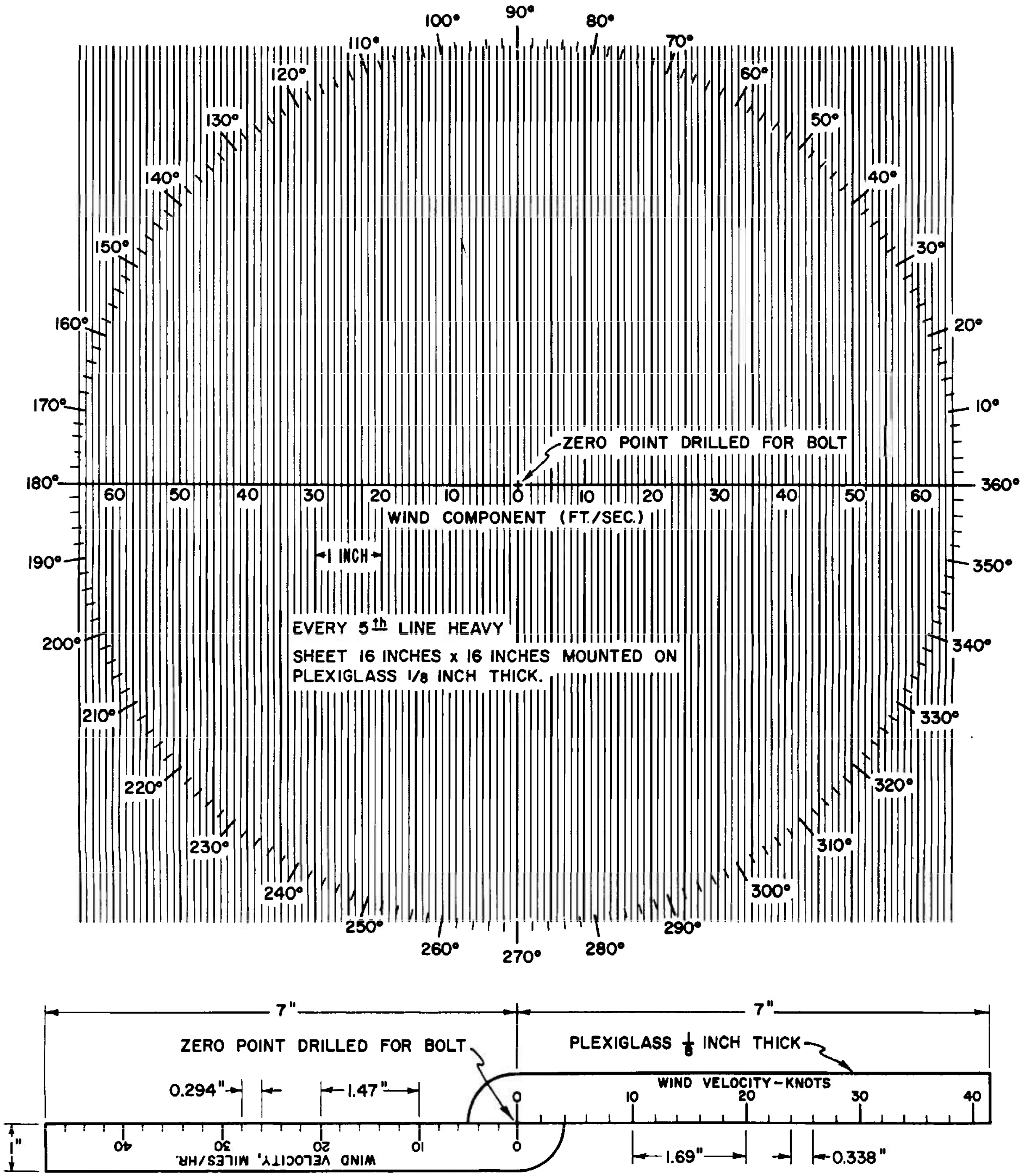


FIG. 7 ELEMENTS AND DIMENSIONS FOR WIND BOARD

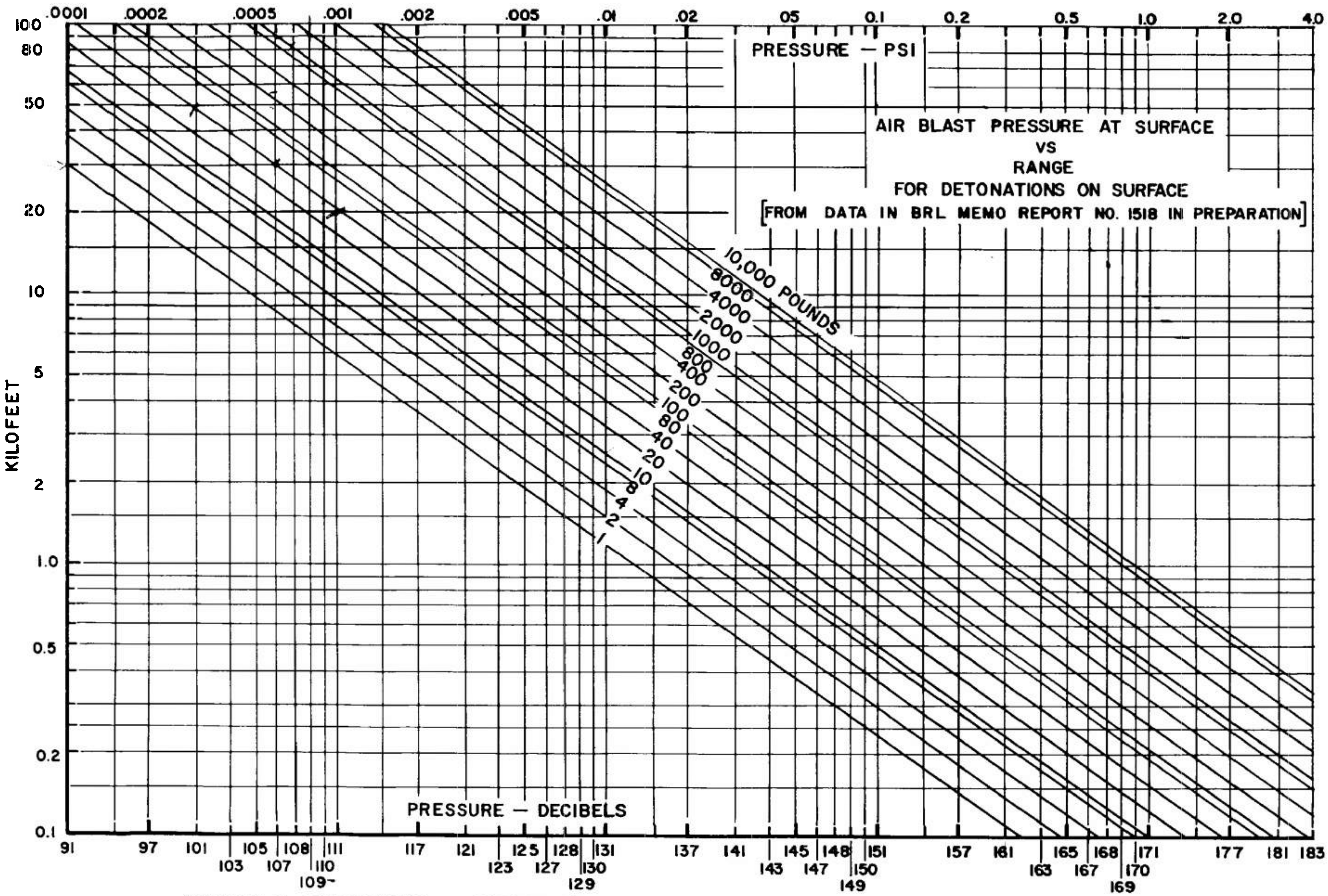
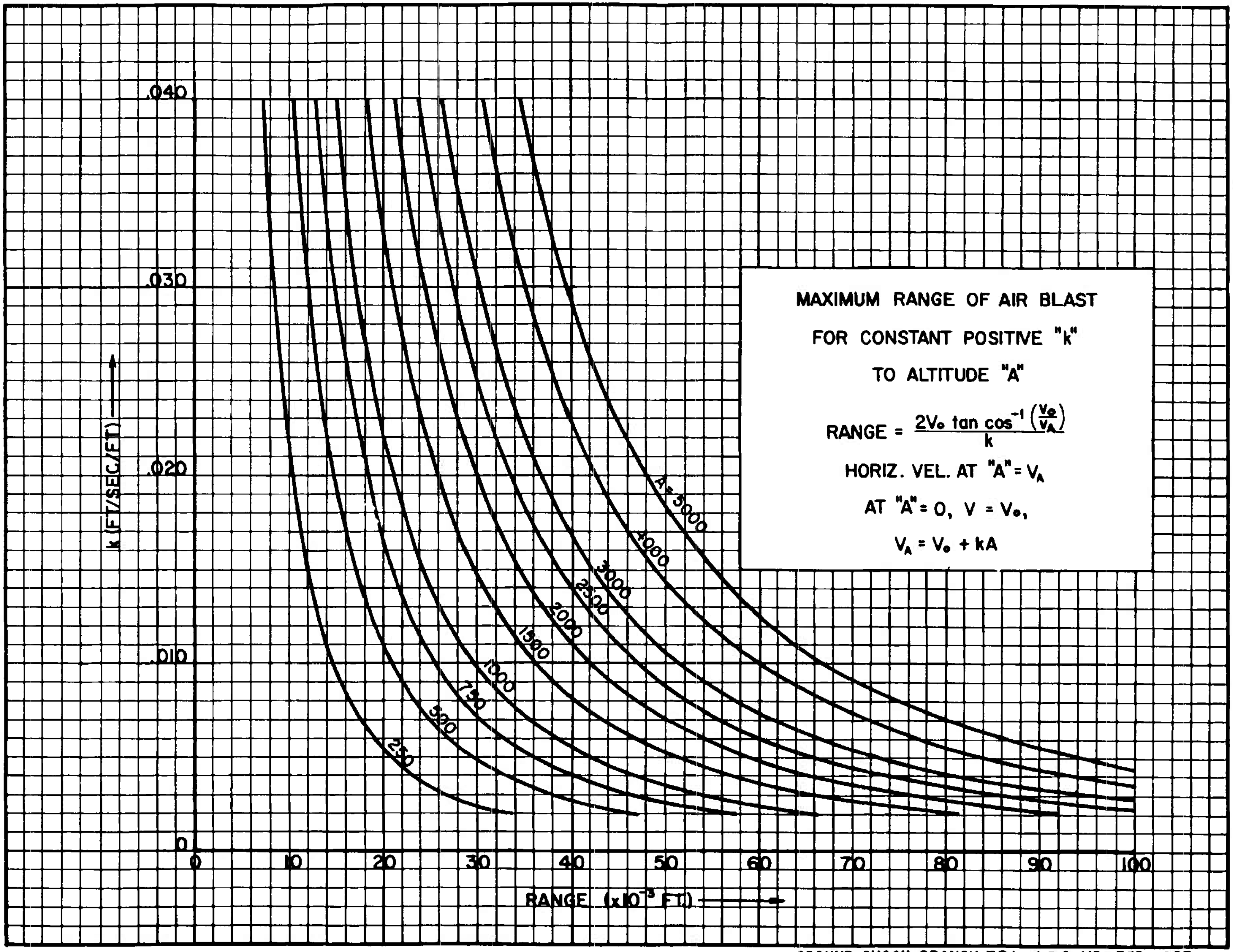


FIGURE 8. PRESSURE vs. DISTANCE WHEN VERTICAL VELOCITY GRADIENT IS ZERO. (1963)



GROUND SHOCK BRANCH, T.B.L., A.P.G., MD., FEB., 1957

FIG. 9 MAXIMUM RANGE OF RAYS WHEN A POSITIVE GRADIENT EXTENDS TO VARIOUS ALTITUDES

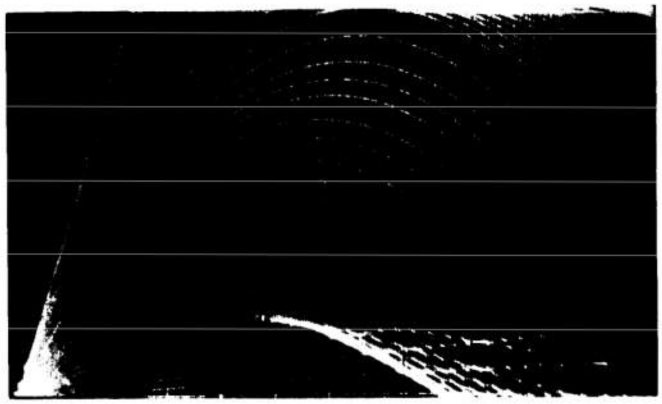


FIG. 10 RAY PATHS WHEN VERTICAL VELOCITY GRADIENT IS ZERO IN THE AIR LAYER CLOSE TO GROUND SURFACE AND POSITIVE IN THE LAYER IMMEDIATELY ABOVE.

FIG. 11 RAY PATHS FOR COMBINATION OF STRONG AND WEAK POSITIVE VELOCITY GRADIENTS IN THE AIR WHEN THE STRONG GRADIENT IS IN LAYER ADJACENT TO THE SURFACE.

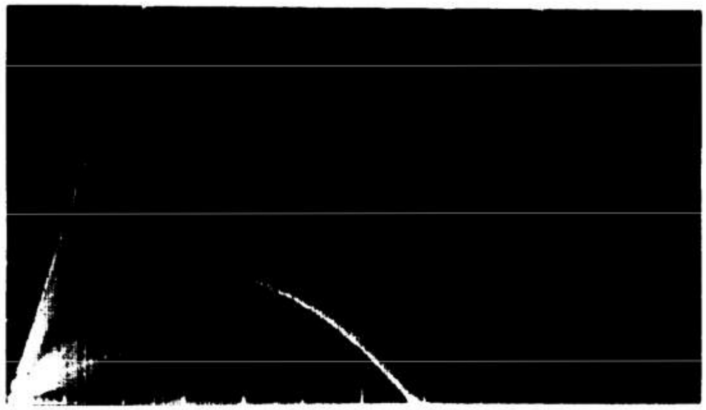


FIG. 12 RAY PATHS FOR COMBINATION OF STRONG AND WEAK POSITIVE VELOCITY GRADIENTS IN THE AIR WHEN THE WEAK GRADIENT IS ADJACENT TO THE SURFACE.

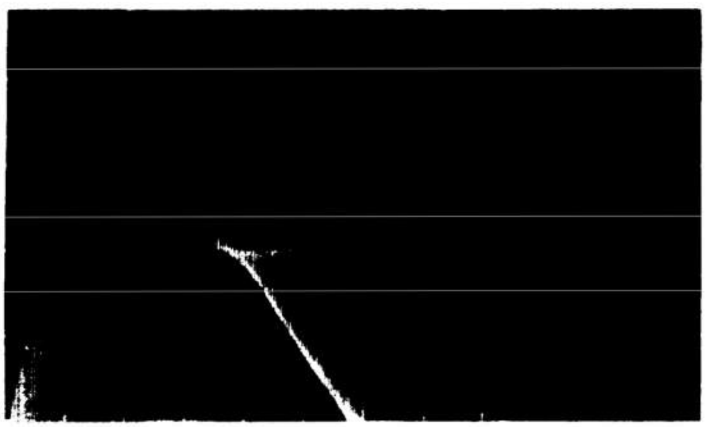


FIG. 13 RAY PATHS IN THE AIR WHEN A POSITIVE VELOCITY GRADIENT OVERLIES A NEGATIVE VELOCITY GRADIENT.

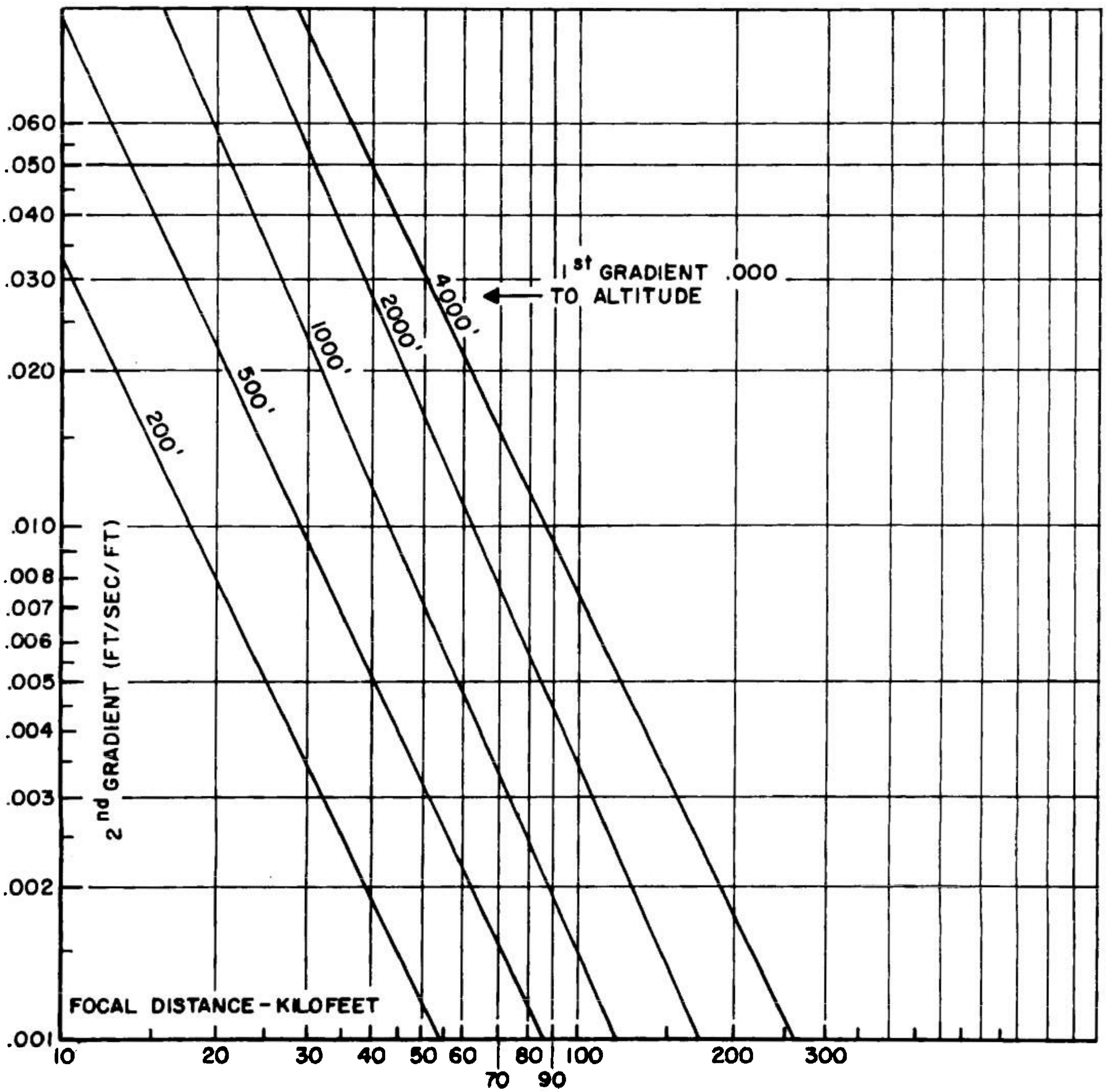


FIG. 14A. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS ZERO TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

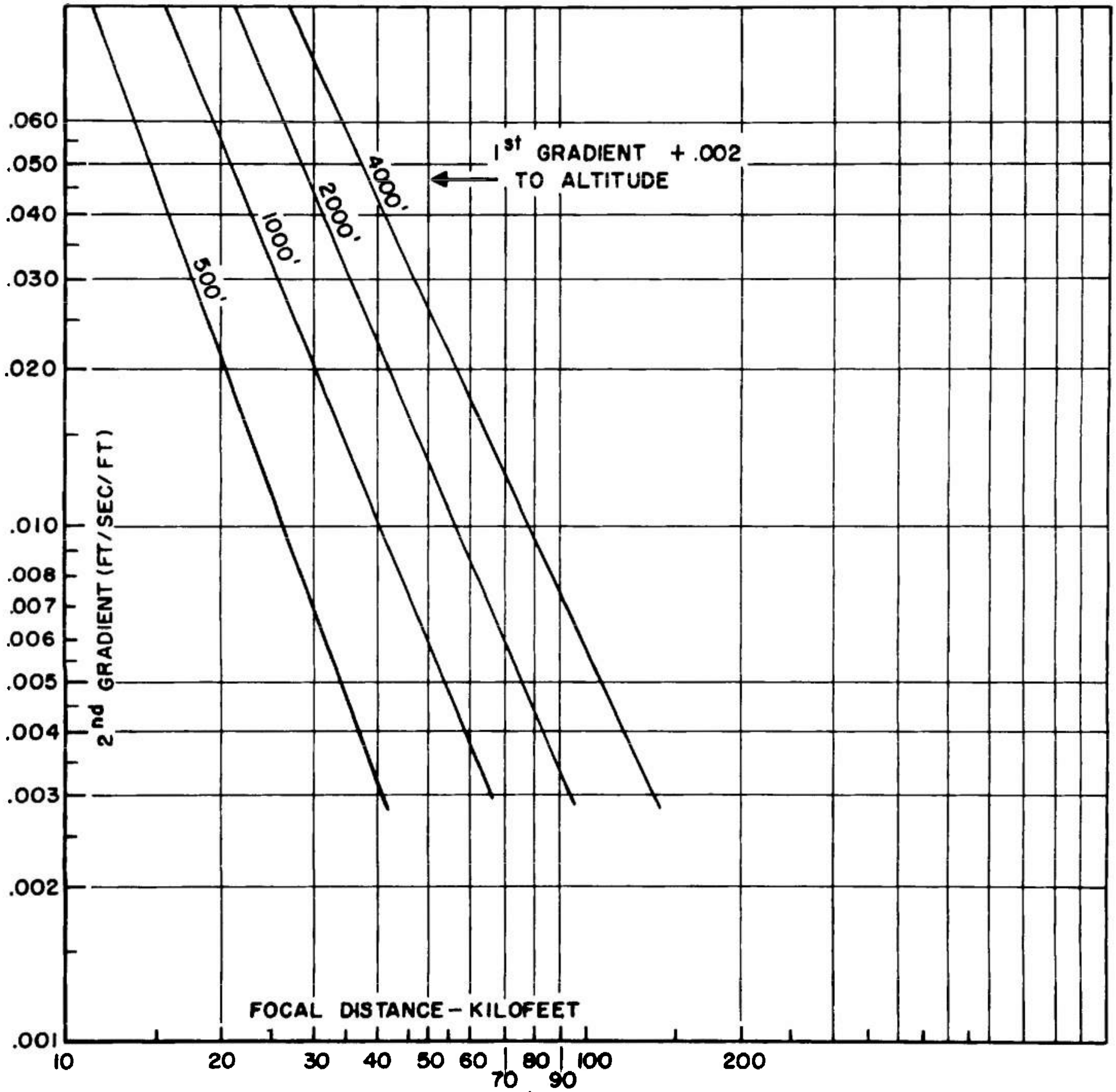


FIG. 14B. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS +.002 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

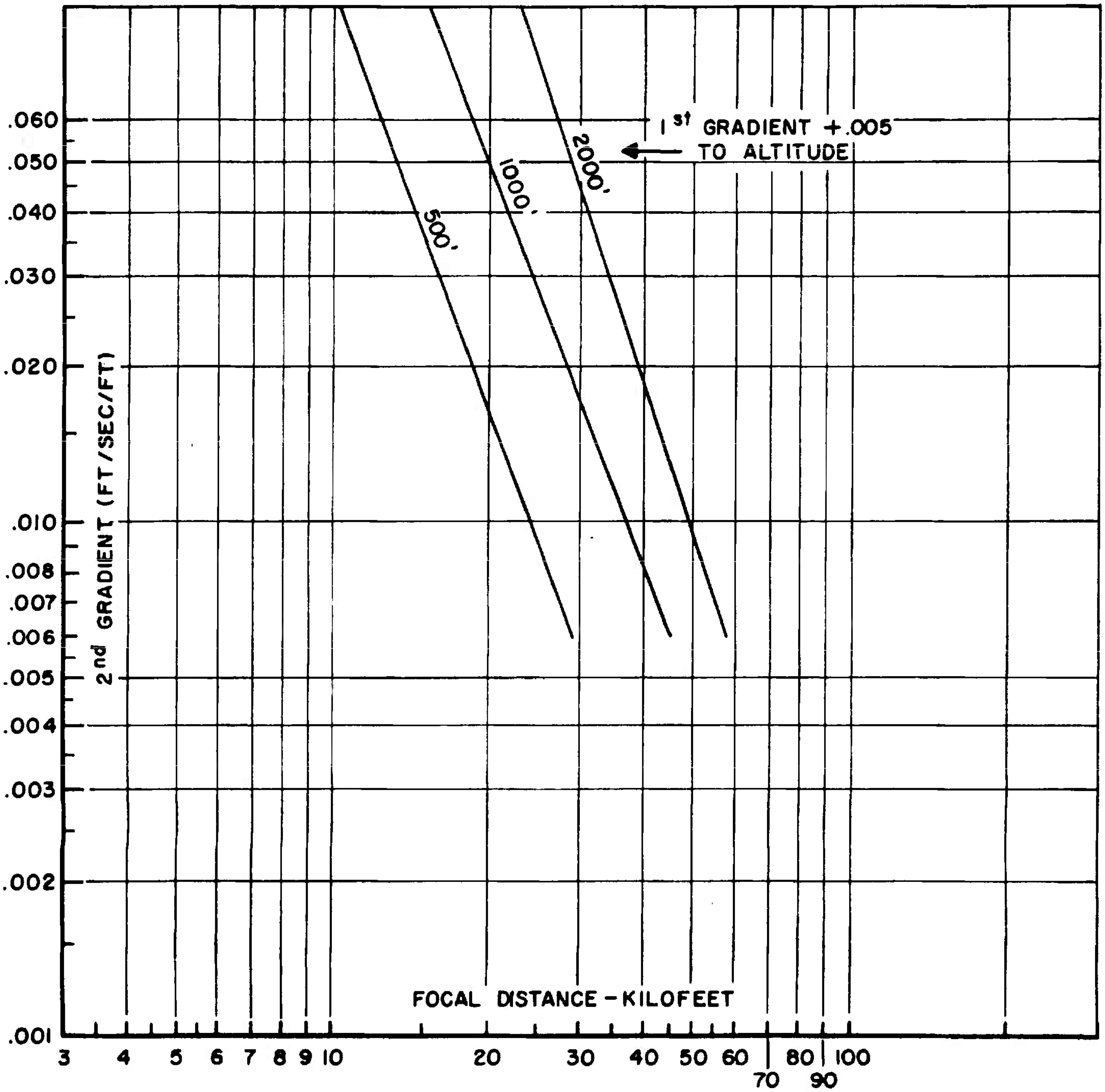


FIG. 14C. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS +.005 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

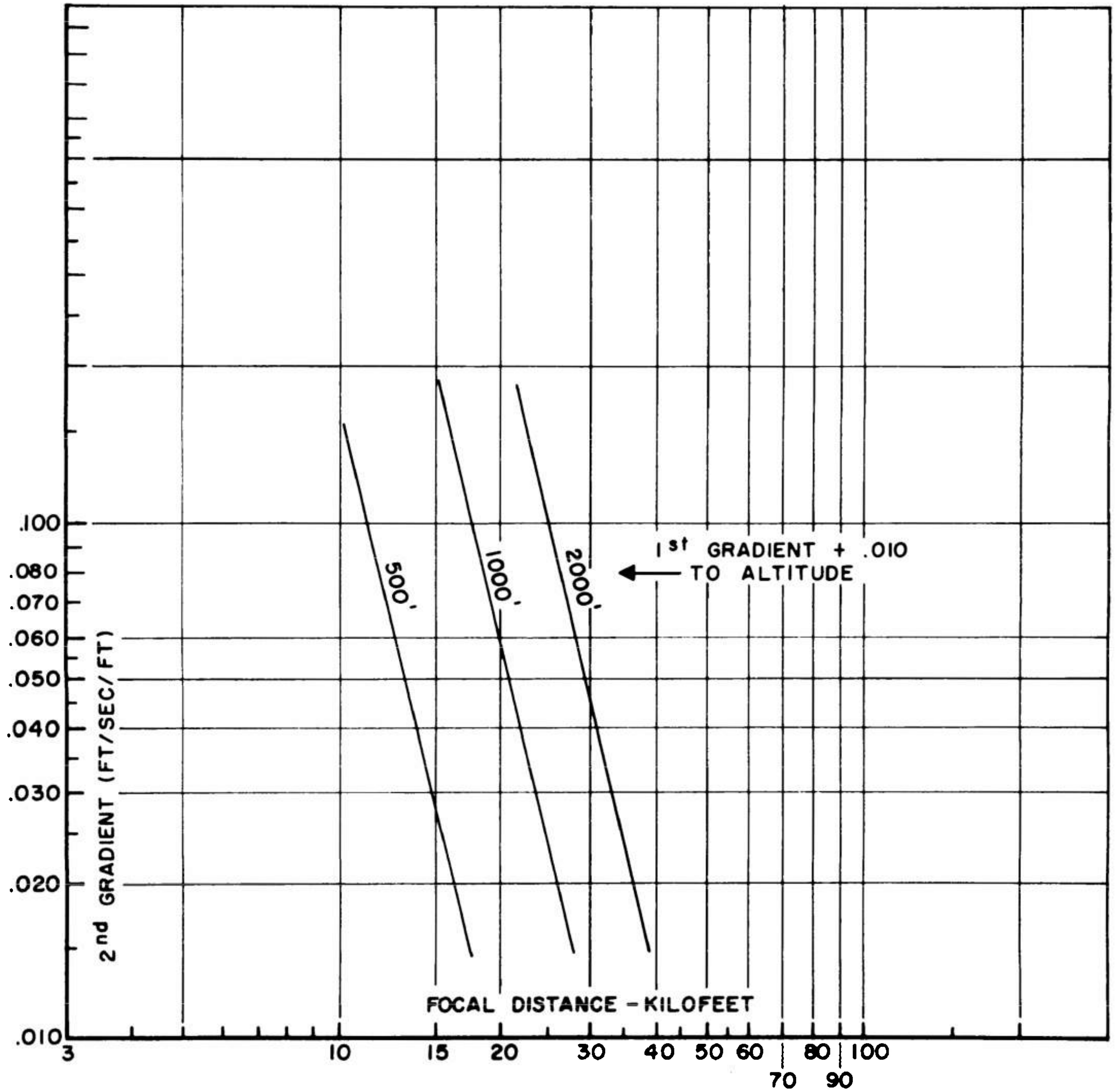


FIG. 14 D. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS +.010 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

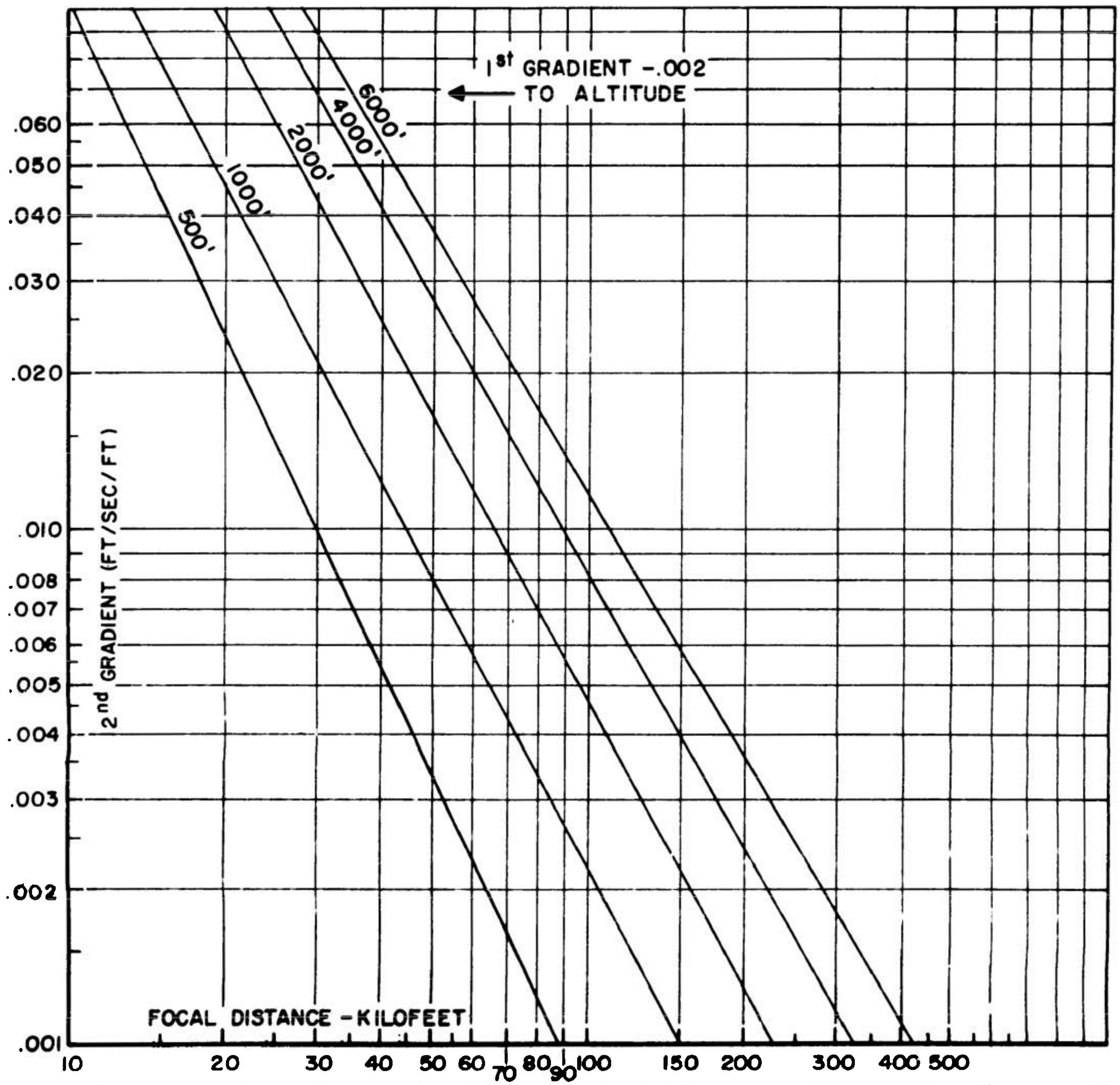


FIG. 14E. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS -.002 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

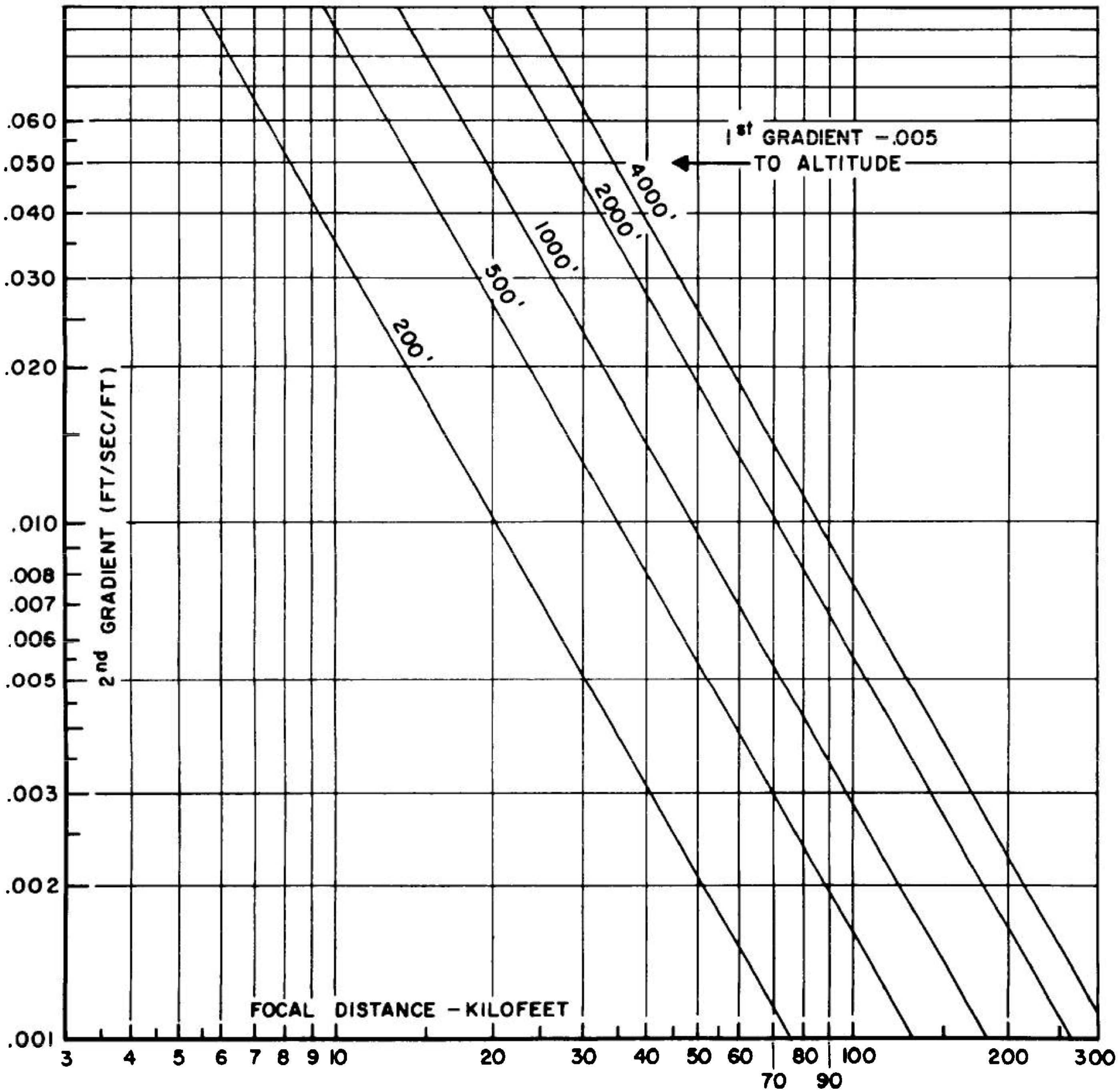


FIG. 14 F. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS -.005 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

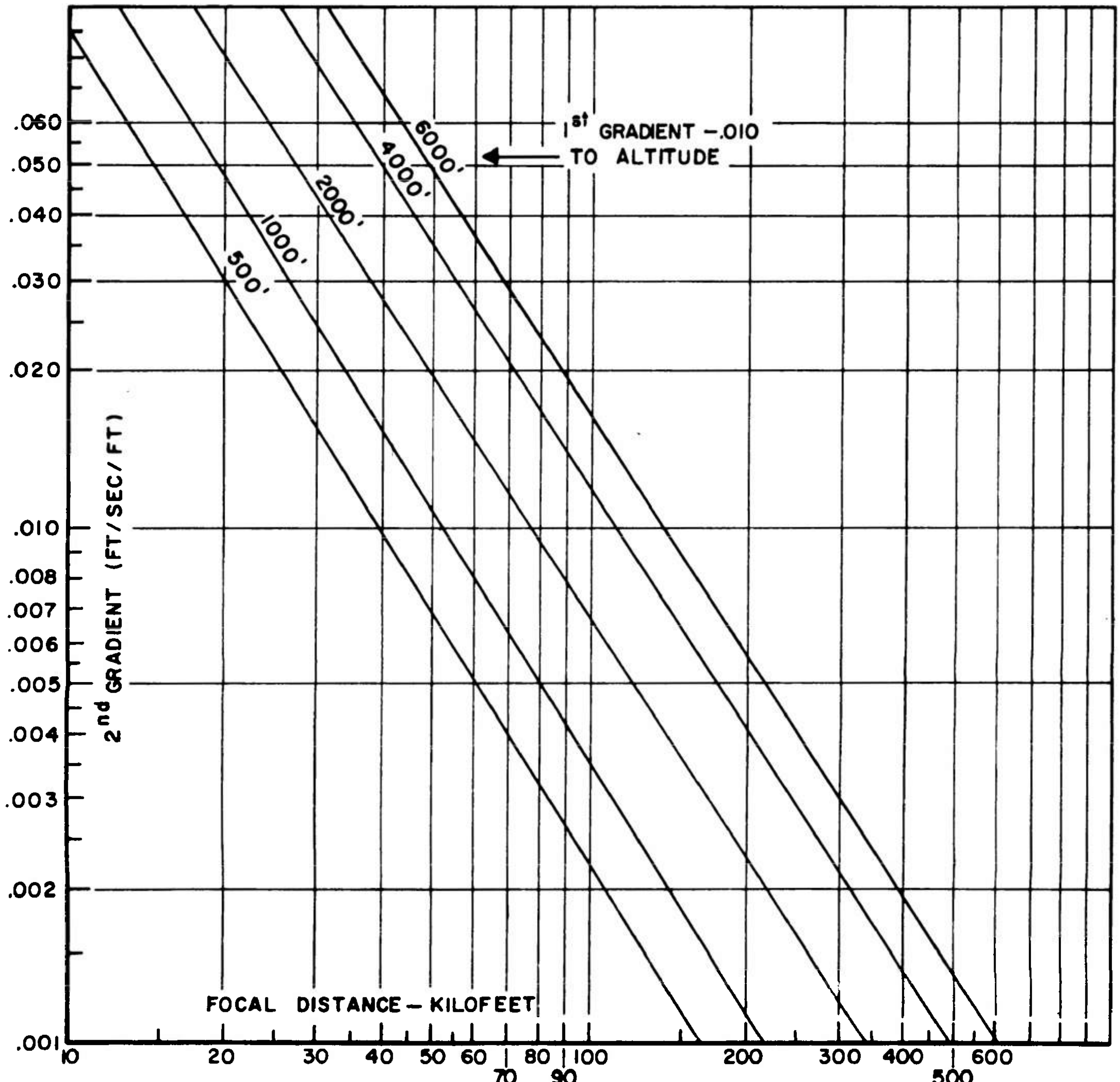


FIG. 14G. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS -.010 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

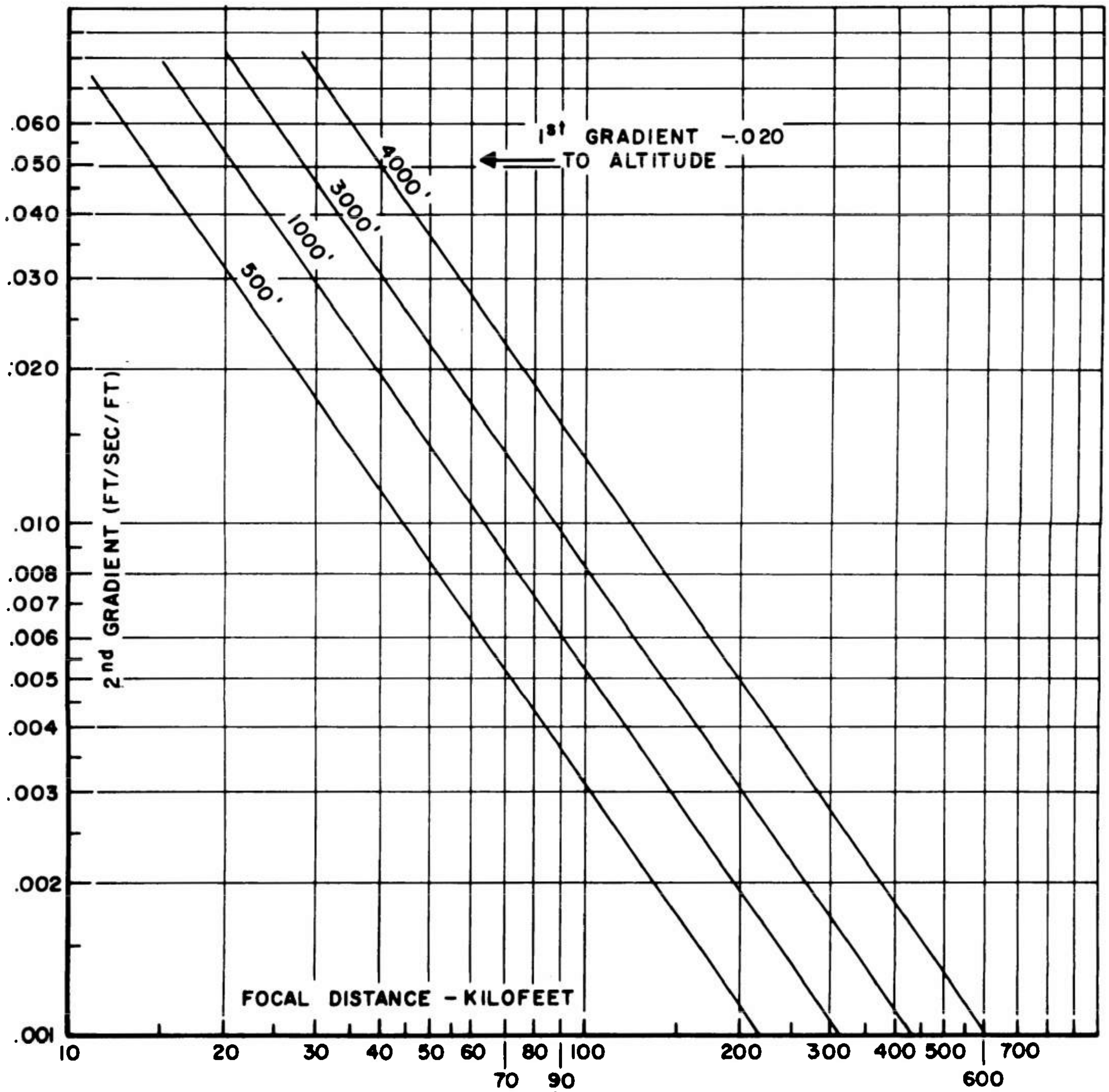


FIG. 14 H FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS -.020 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

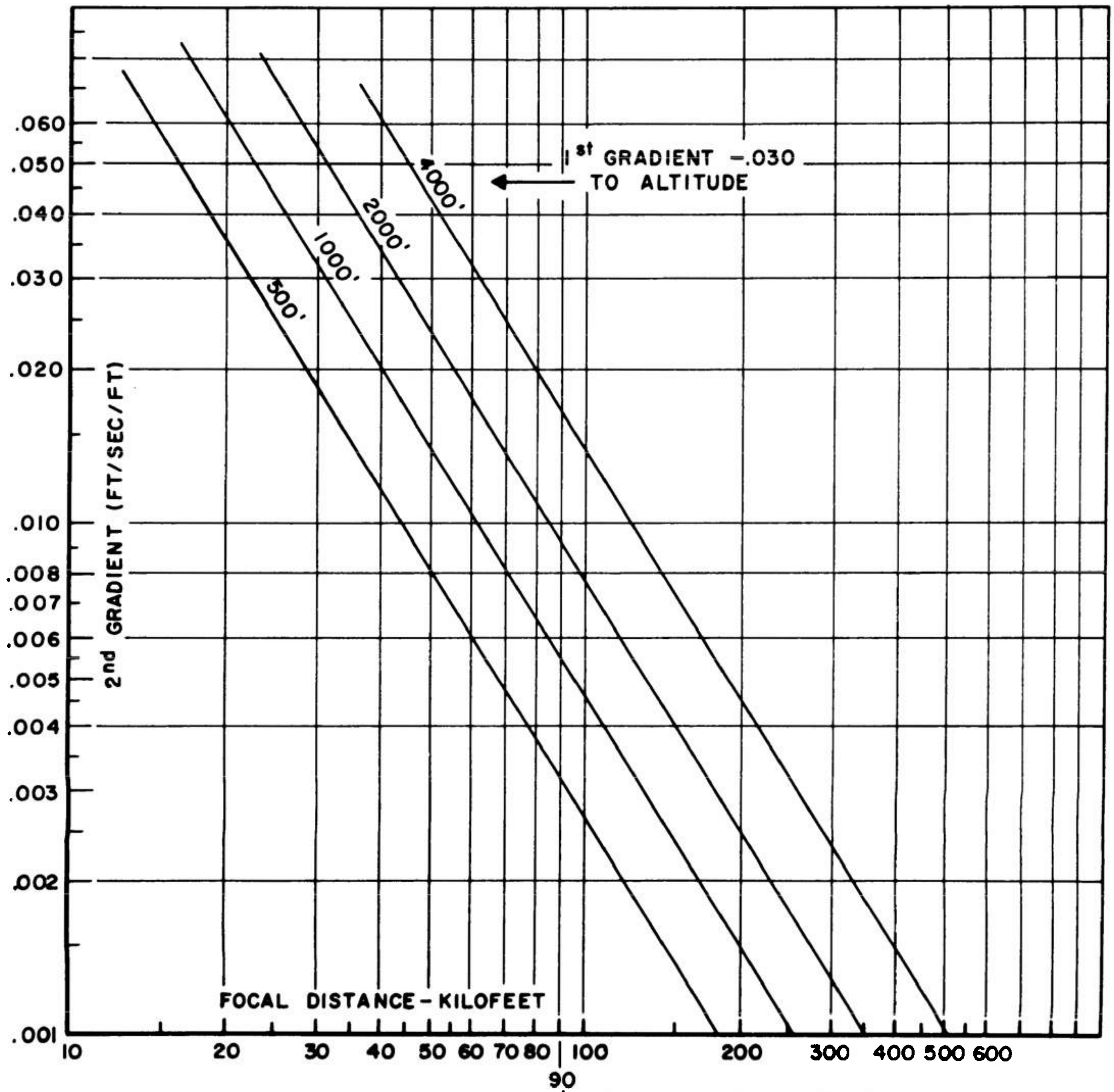


FIG. 14I. FOCAL DISTANCE WHEN 1st VELOCITY GRADIENT IS -.030 FT/SEC/FT TO VARIOUS ALTITUDES AND FOR VARIOUS 2nd GRADIENTS

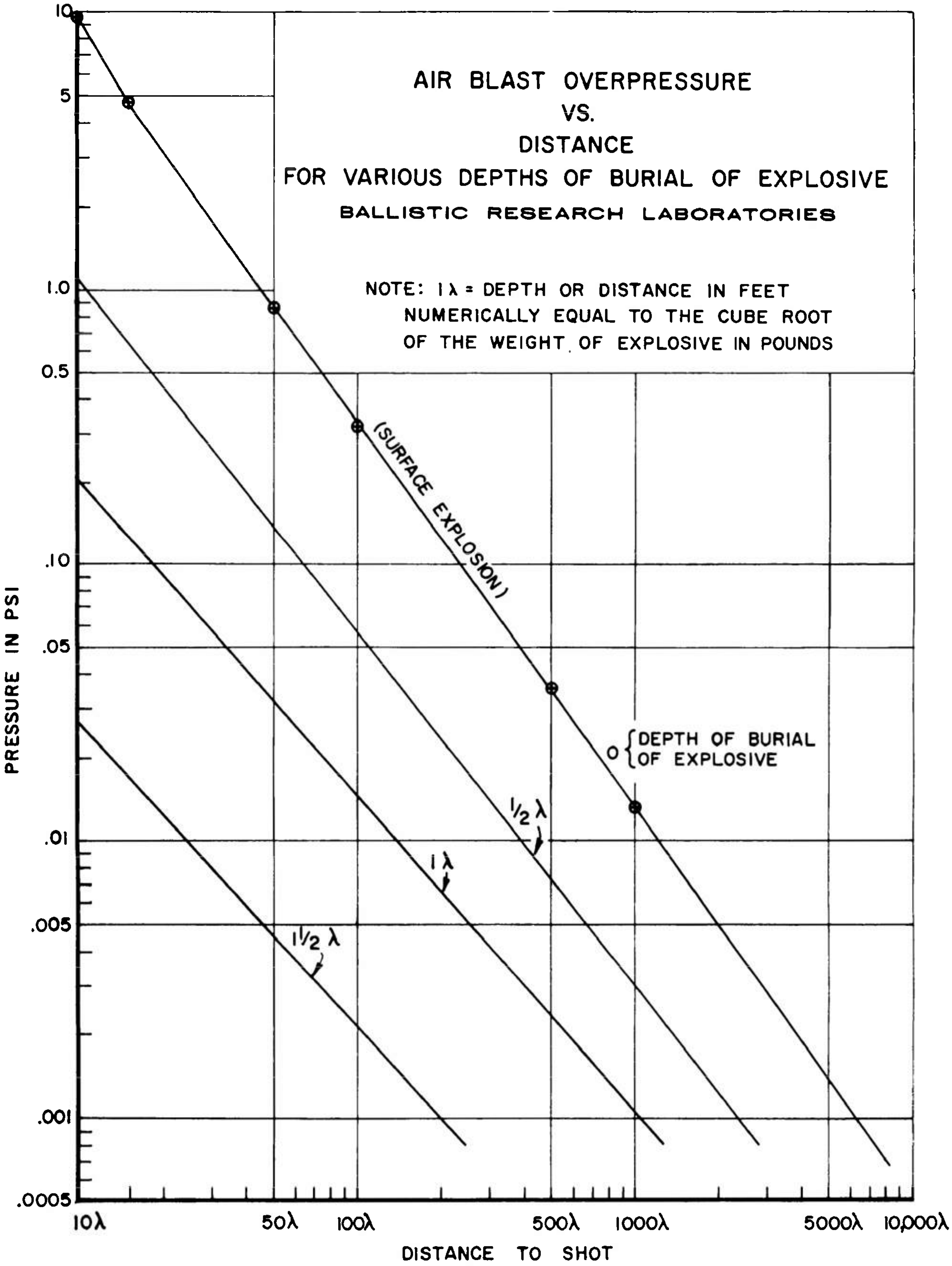


FIGURE 15 — SUPPRESSION OF AIR BLAST OVERPRESSURE BY BURIAL OF EXPLOSIVE

APPENDIX A

EVALUATION AIDS

Convenient references for quickly evaluating the meteorological conditions that determine the pattern of ray paths are:

1. Categories of gradients and multiplying factors.

2. Air Blast Pressure vs Distance Chart for a uniform atmosphere.

3. Air Blast Pressure vs Distance for Various Depths of Burial of Explosives.

4. Maximum Range of Air Blast for Single Positive Gradient.

These evaluation aids are presented on the following pages.

The meteorological conditions are generally determined by a radiosonde flight at a single location. Gradients at other points between the point of detonation and the focus will vary from the one determined. Furthermore successive flights at the same location will show some changes with time. However the general pattern of the gradients (Category) will not change for several hours unless a weather front is moving in. For this reason the multiplying factor given for each category is chosen to provide the maximum pressure to be expected under the given conditions.

This provides a safety factor in protecting the public and preserving public relations.

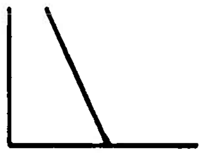
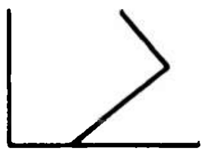
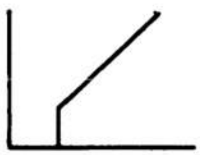
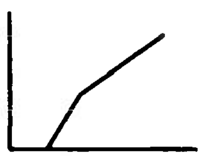
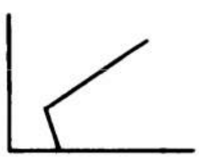
COMBINATION OF GRADIENTS		MULTIPLICATION FACTOR FOR REGION NOTED
SINGLE NEGATIVE GRADIENT		0 – FROM ORIGIN TO LIMIT OF OBSERVATION
POSITIVE GRADIENT NEAR SURFACE WITH NEGATIVE GRADIENT ABOVE.		5 – ORIGIN TO LIMITING RANGE
ZERO GRADIENT NEAR SURFACE WITH POSITIVE GRADIENT ABOVE.		10 – FOCAL AREA ONLY
WEAK POSITIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE		25 – FOCAL AREA ONLY
NEGATIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE		100 – FOCAL AREA ONLY

FIGURE A1 – VARIOUS TYPES OF VELOCITY GRADIENTS TO BE EXPECTED AND THE INCREASE IN INTENSITY AT A FOCUS FOR EACH TYPE

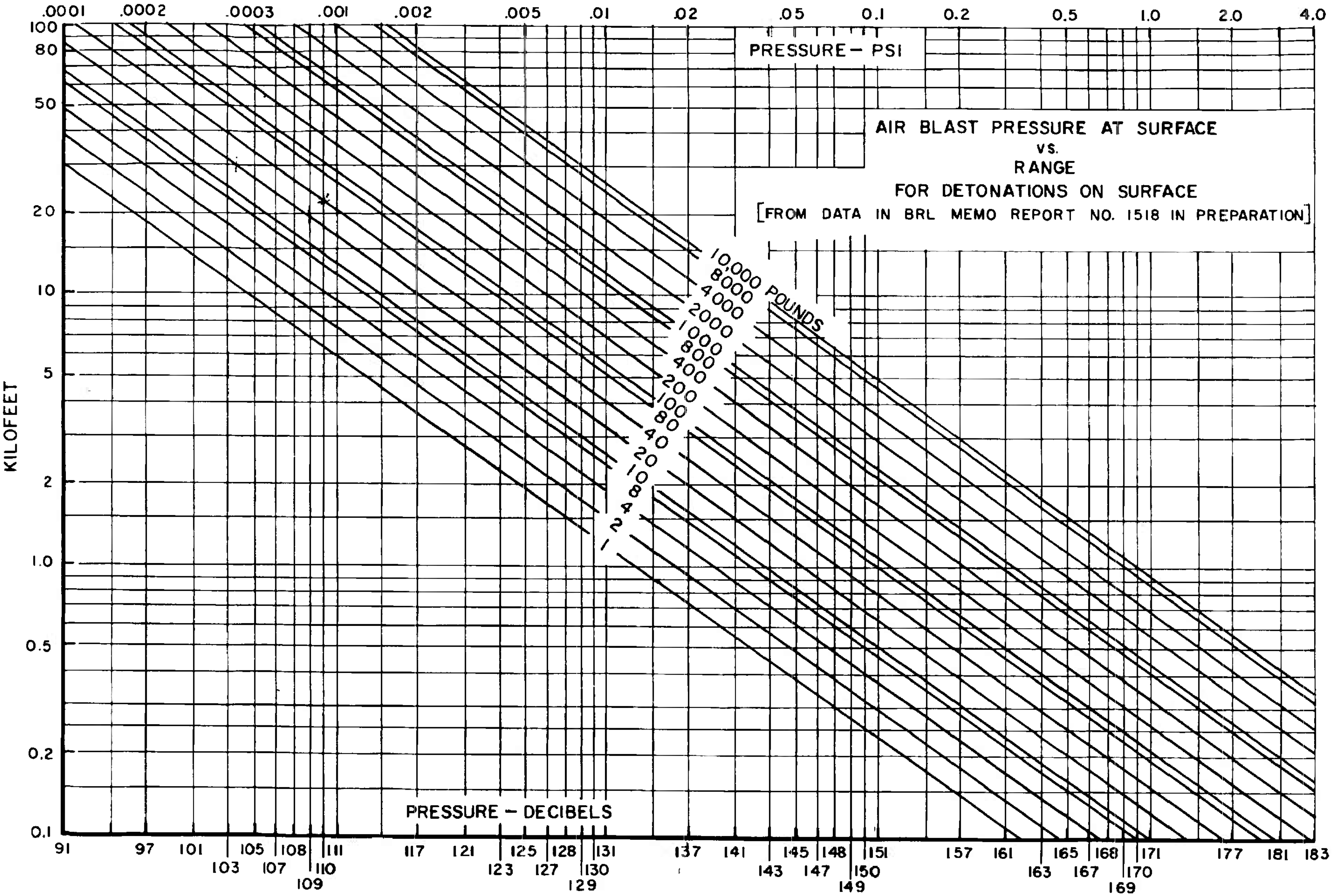


FIGURE A2- PRESSURE vs. DISTANCE WHEN VERTICAL VELOCITY GRADIENT IS ZERO. (1963)

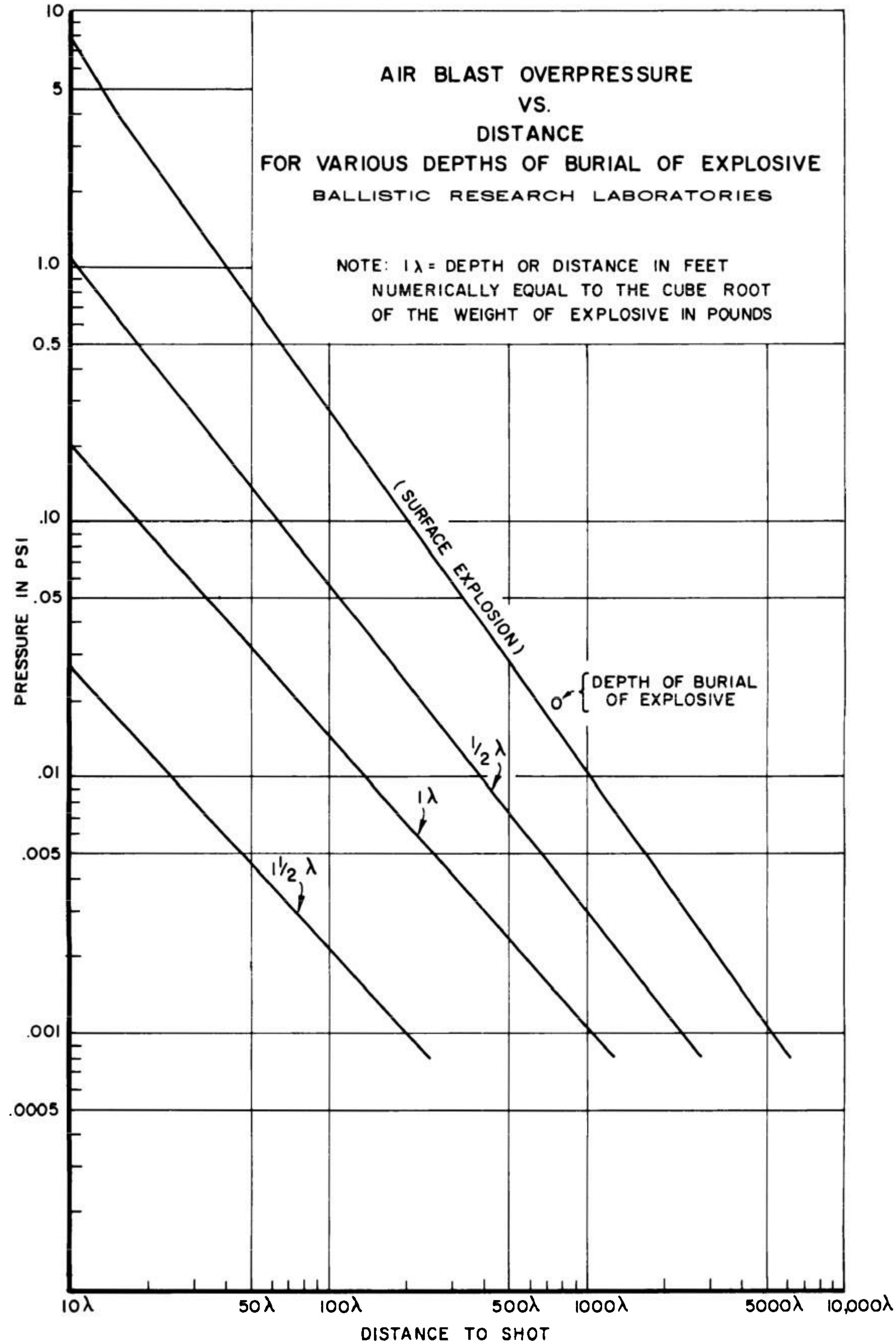


FIGURE A3-SUPPRESSION OF AIR BLAST OVERPRESSURE BY BURIAL OF EXPLOSIVE

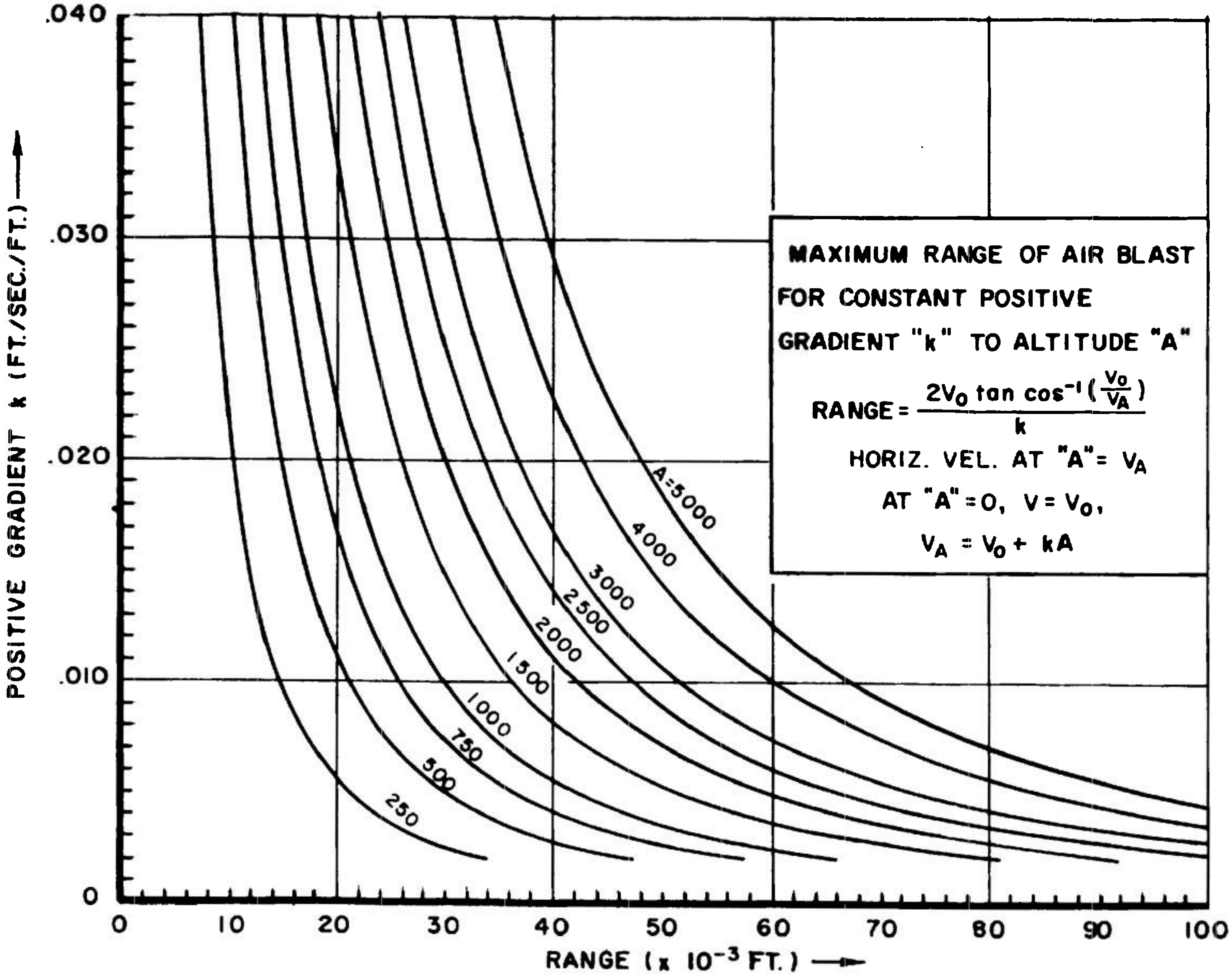


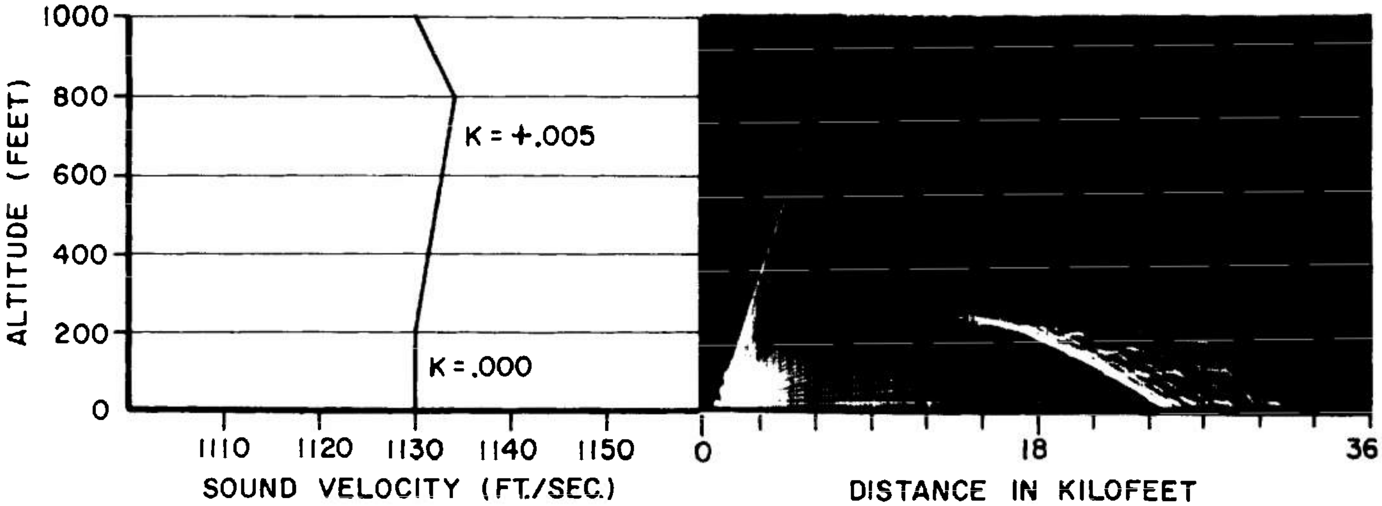
FIGURE A4 - MAXIMUM RANGE OF RAYS WHEN A POSITIVE GRADIENT EXTENDS TO VARIOUS ALTITUDES

APPENDIX B

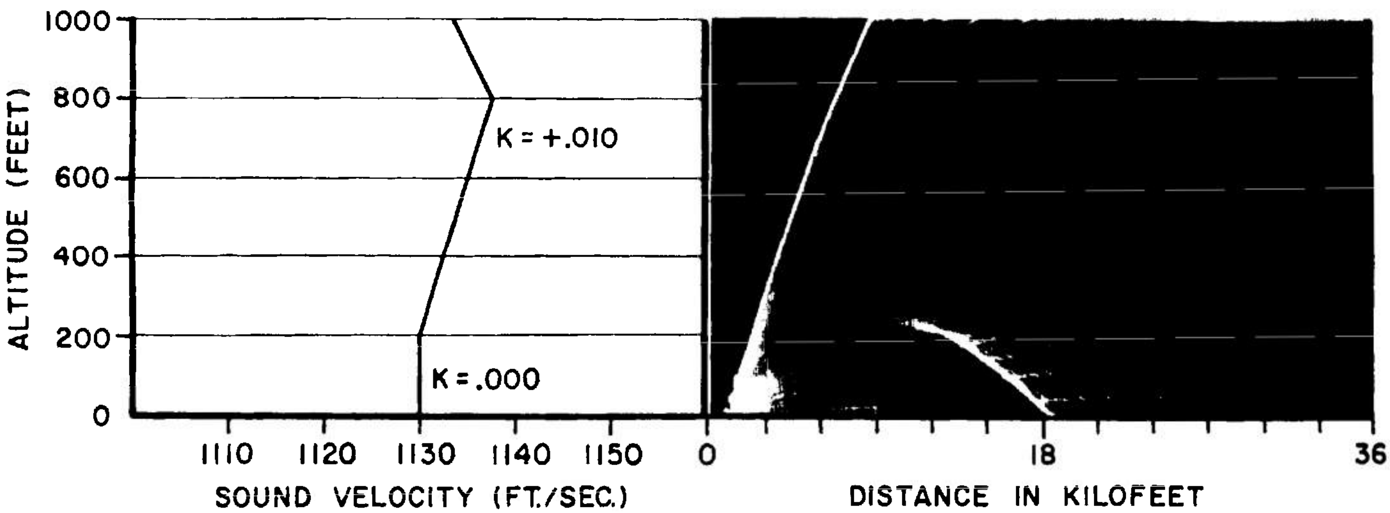
LIBRARY OF CASES

The following pages present a set of vertical velocity gradients which should cover most of the conditions to be expected throughout the United States. The velocity at each altitude was determined from the temperature and wind velocity. Sound Ray Paths are shown for each velocity versus altitude curve. These have been computed on the Sperry-Rand Electronic Ray Plotter. The pattern of these paths shows whether or not a focus occurs and the distance to the focus if one does occur.

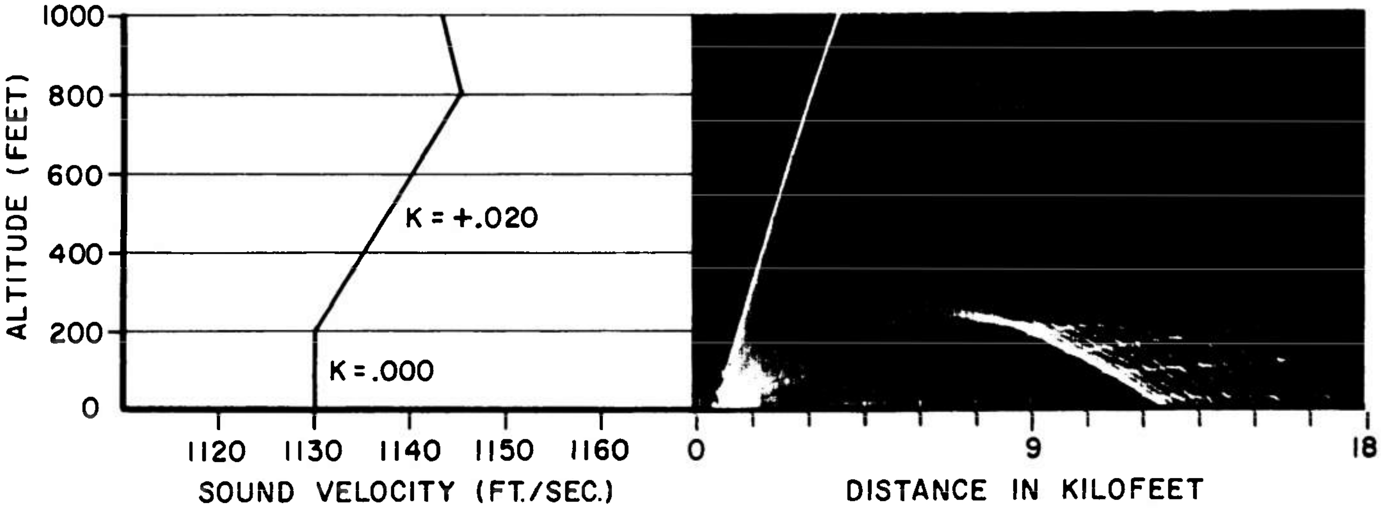
Note: Altitudes are in feet in cases 1 to 4 and 72 to 75. In all other cases the altitudes are stated in kilofeet.



CASE NUMBER 1



CASE NUMBER 2



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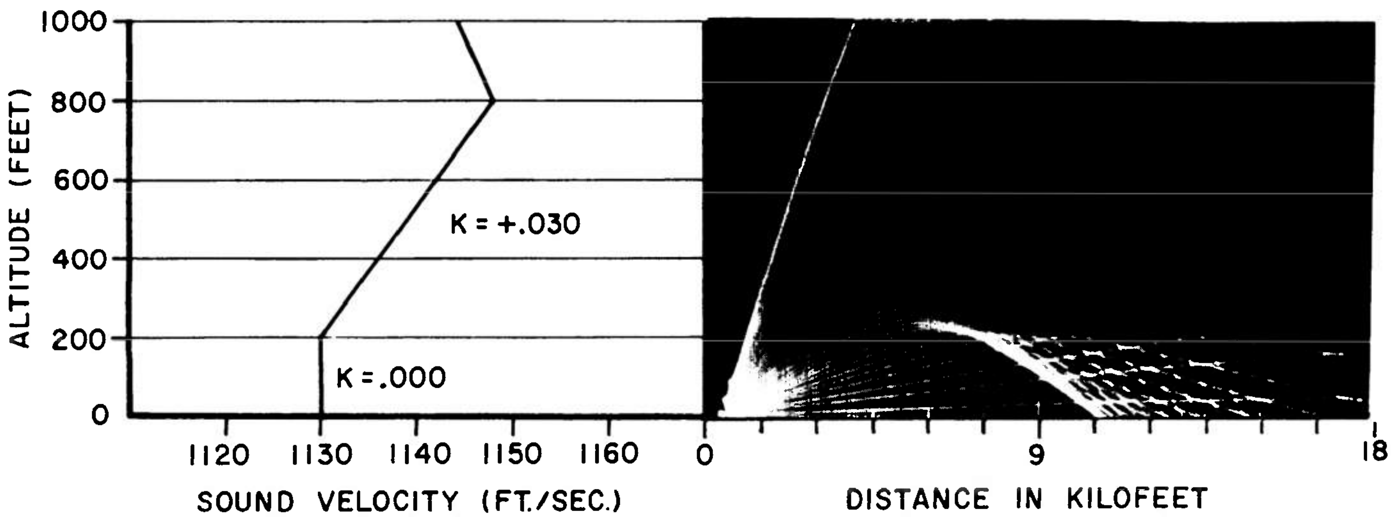
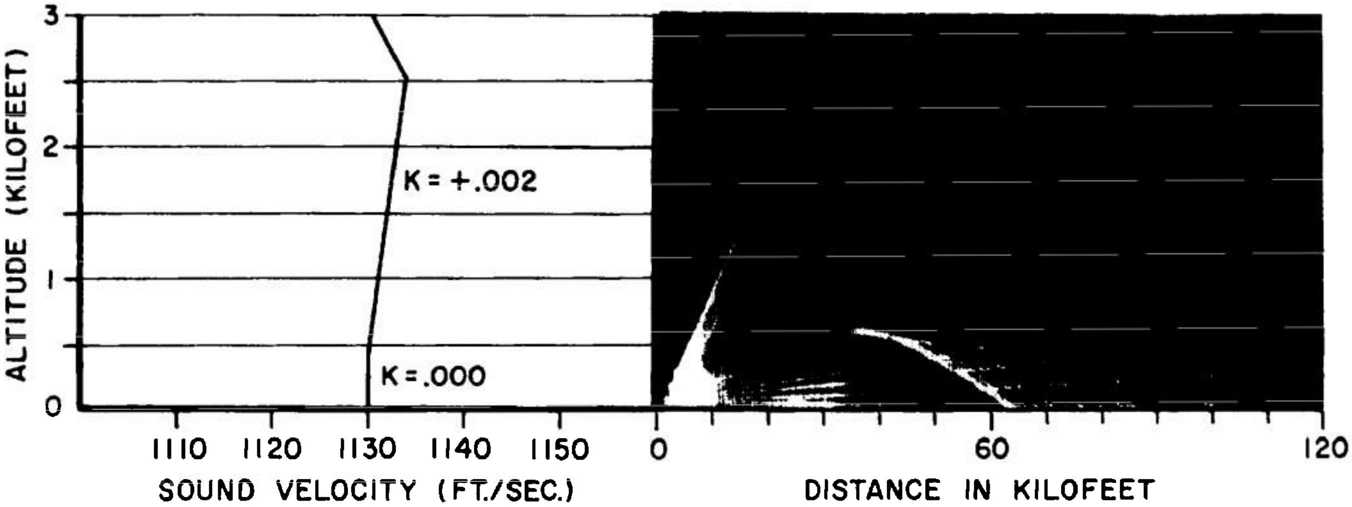


CASE NUMBER 4



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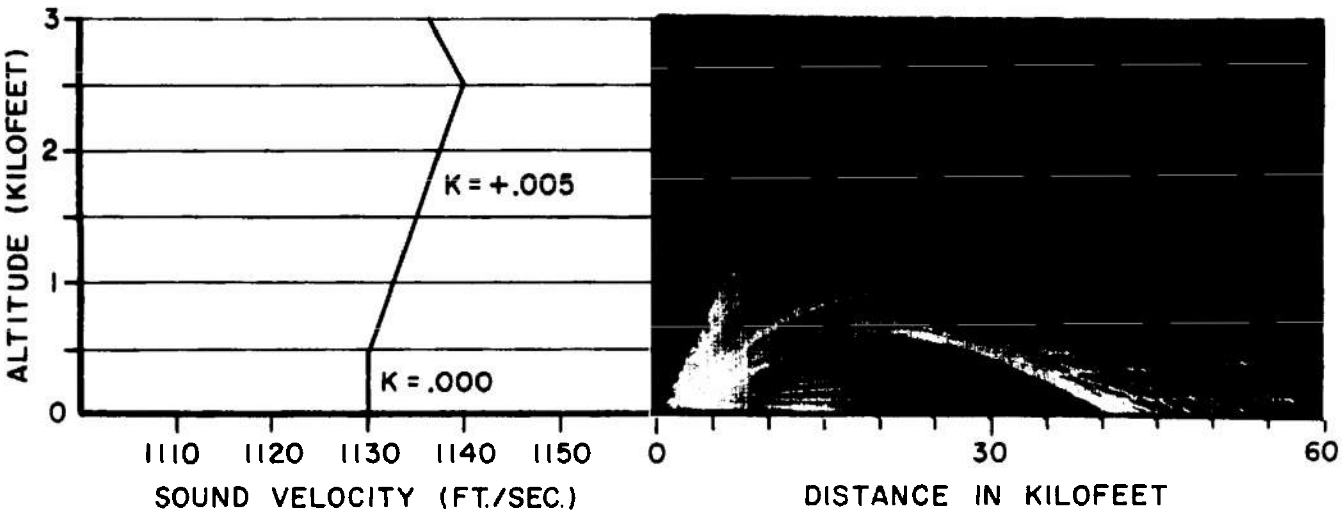

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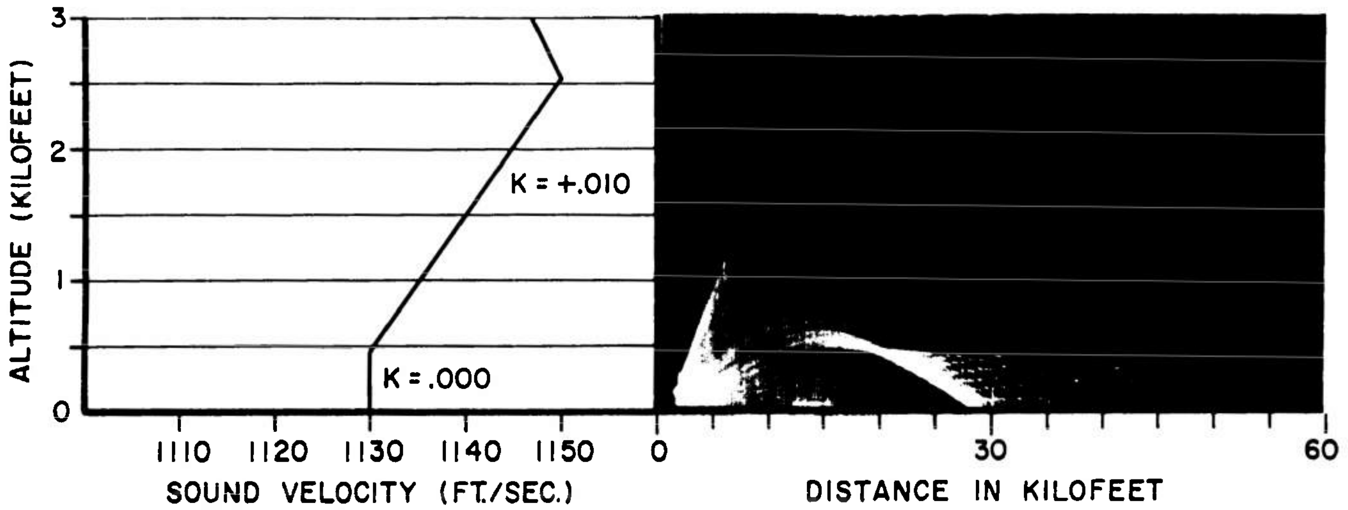

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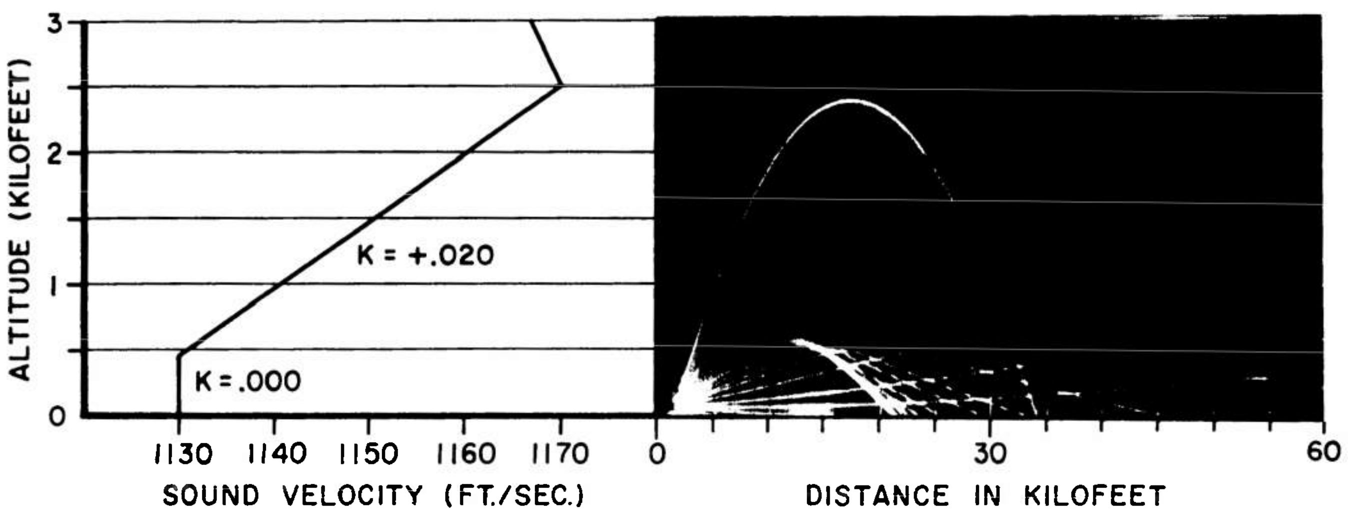

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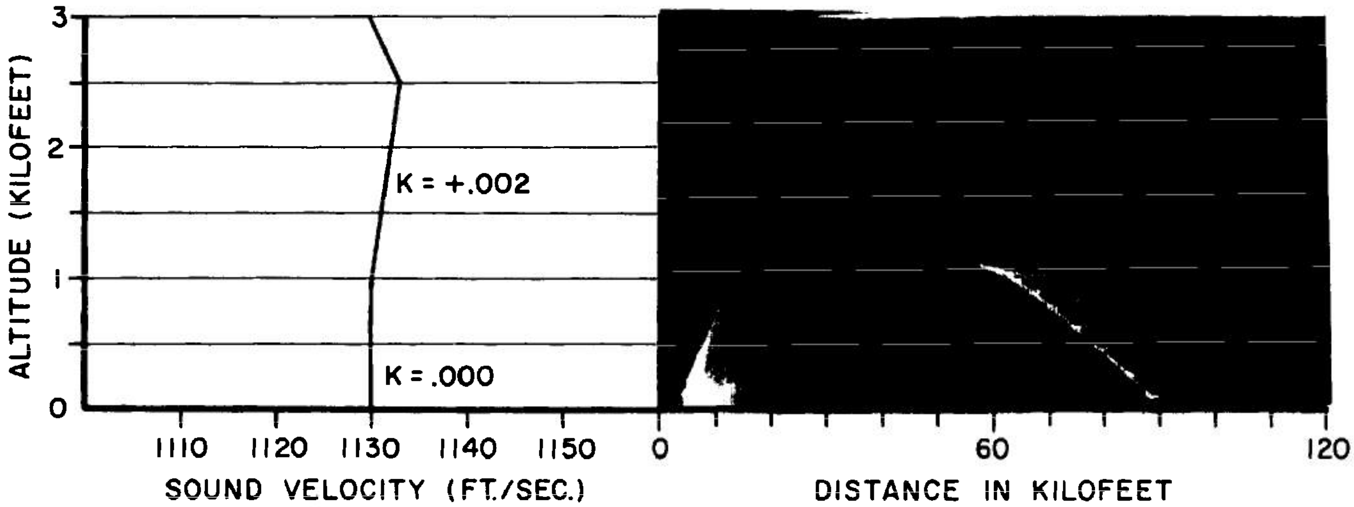

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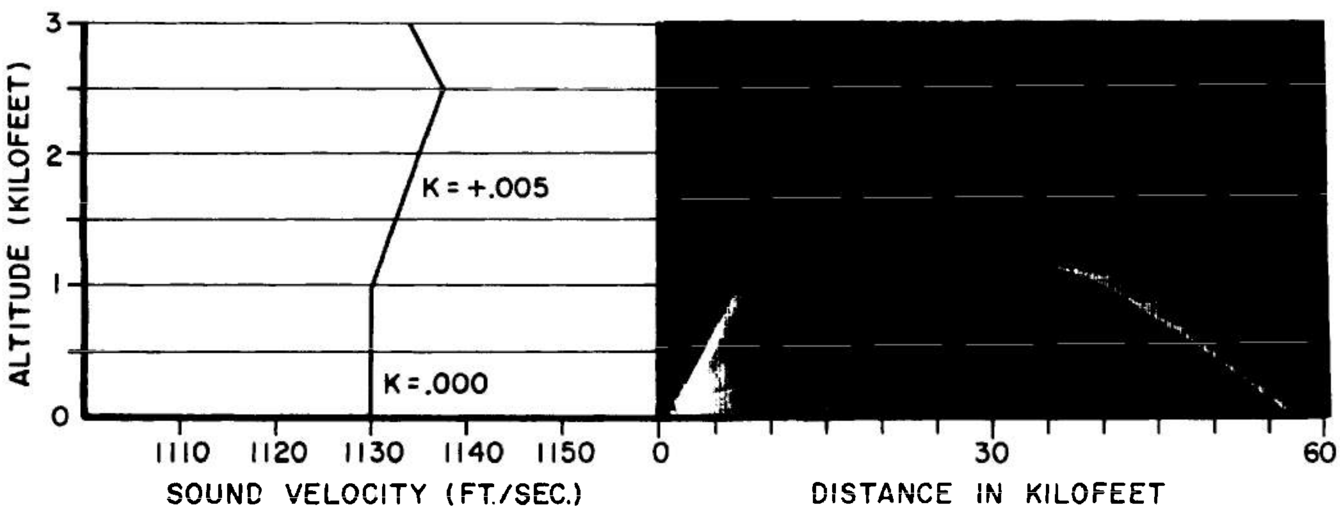

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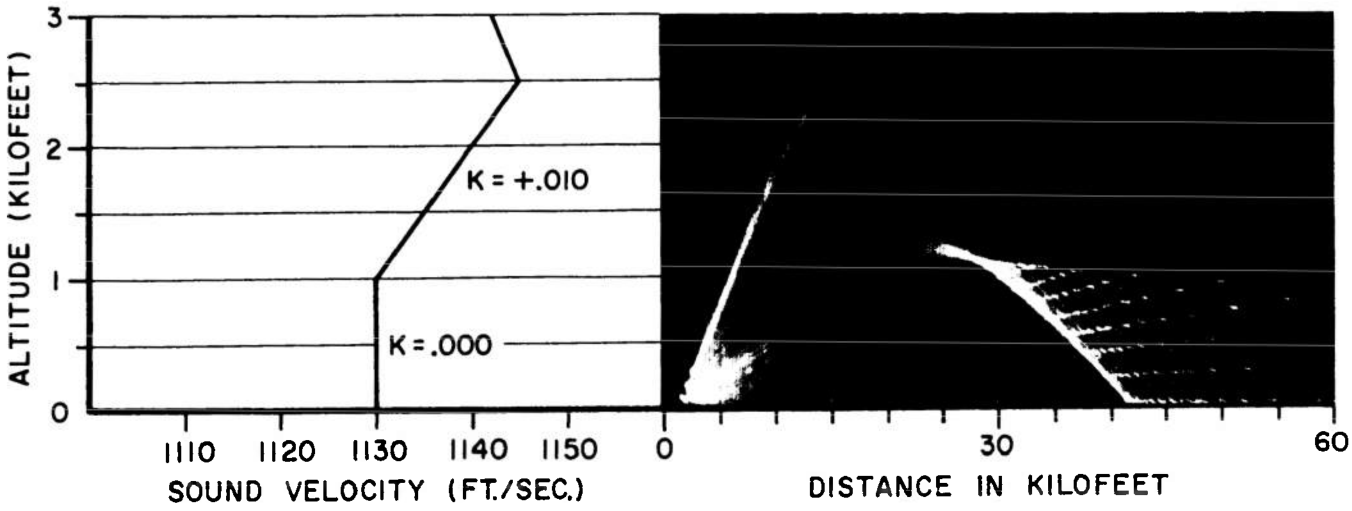
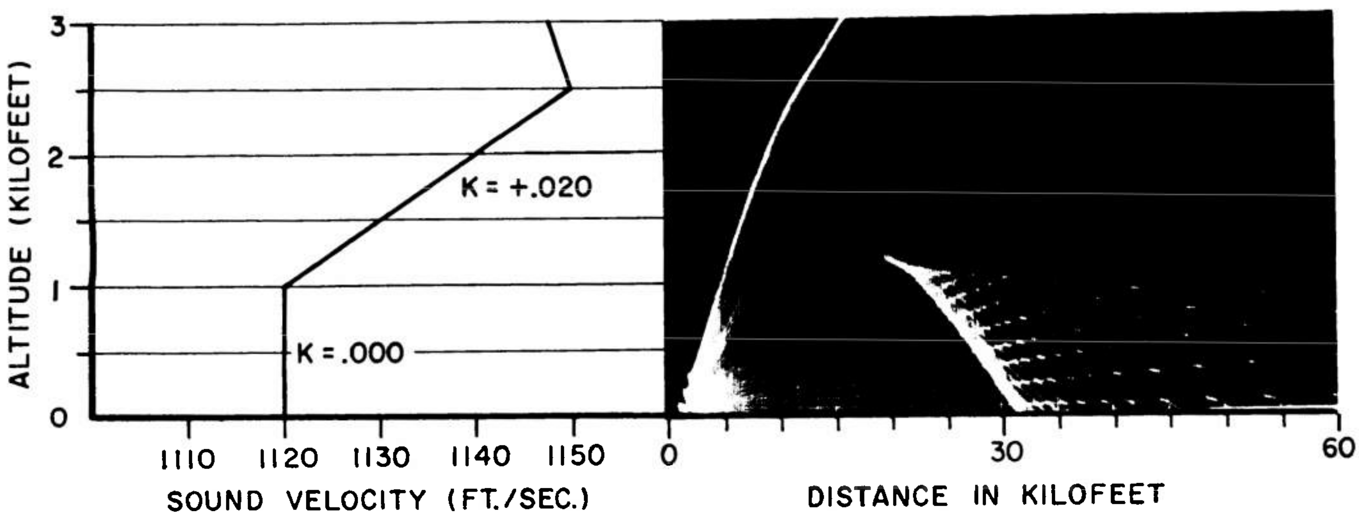


CASE NO. 11



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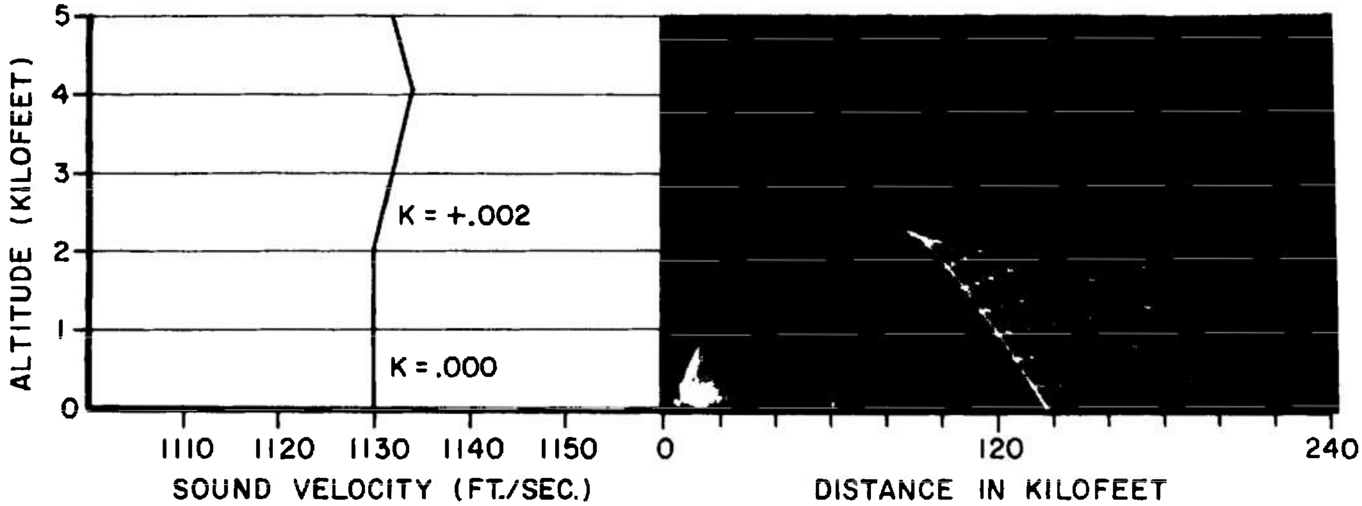

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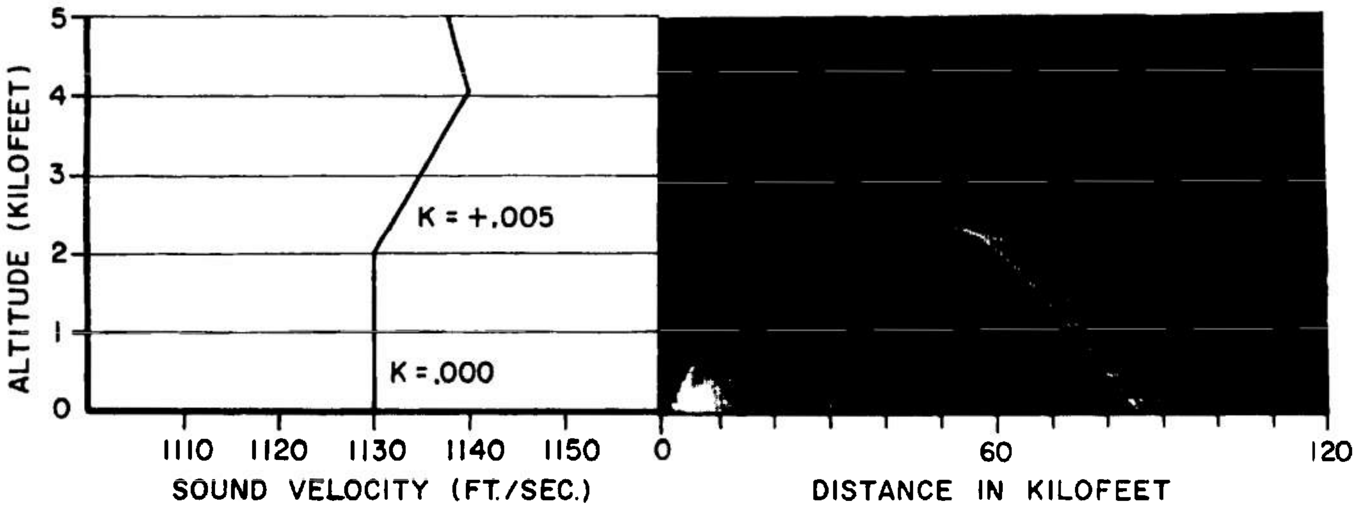

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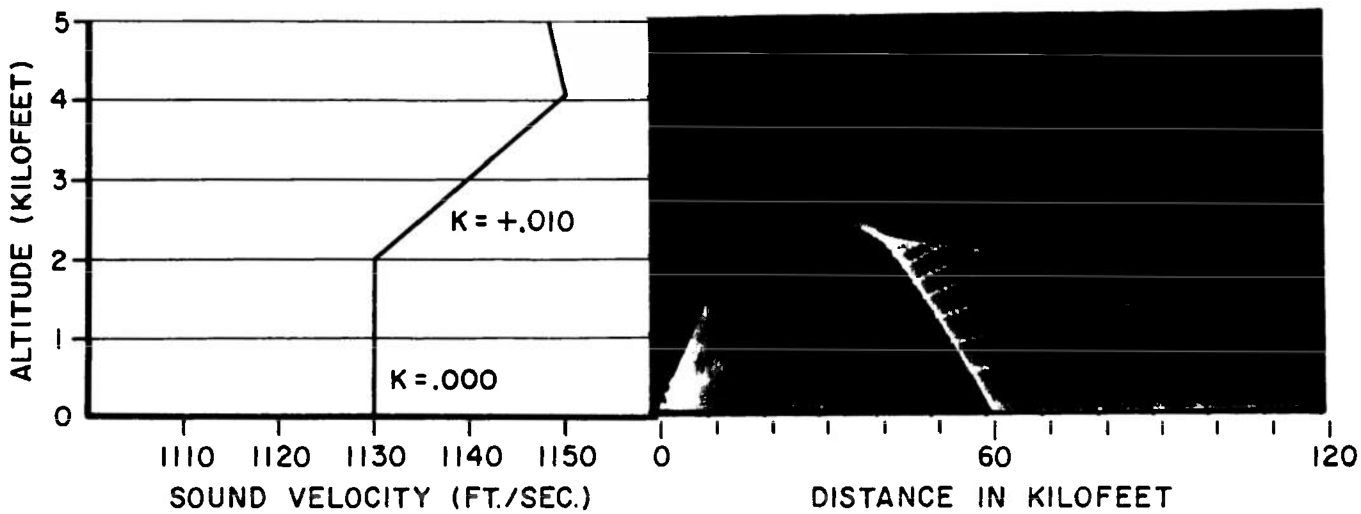

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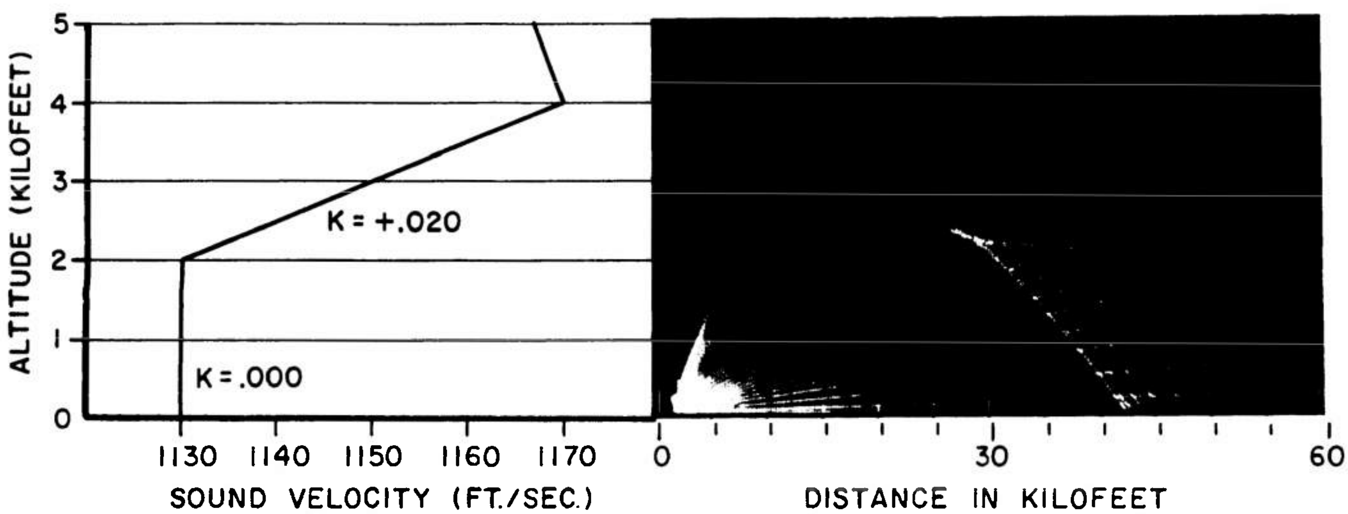

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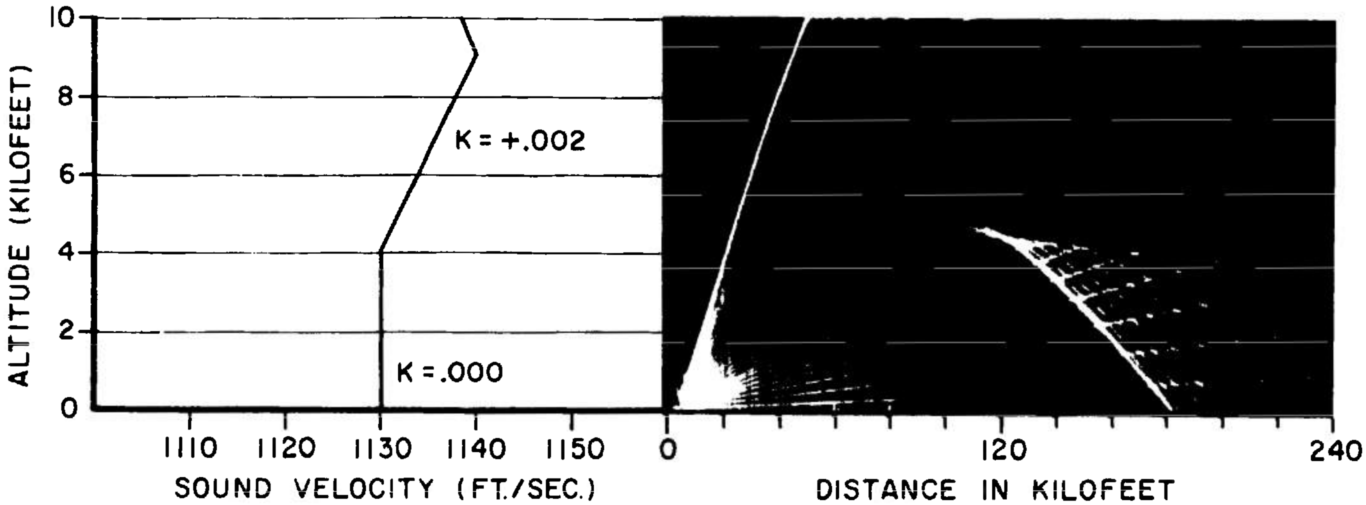

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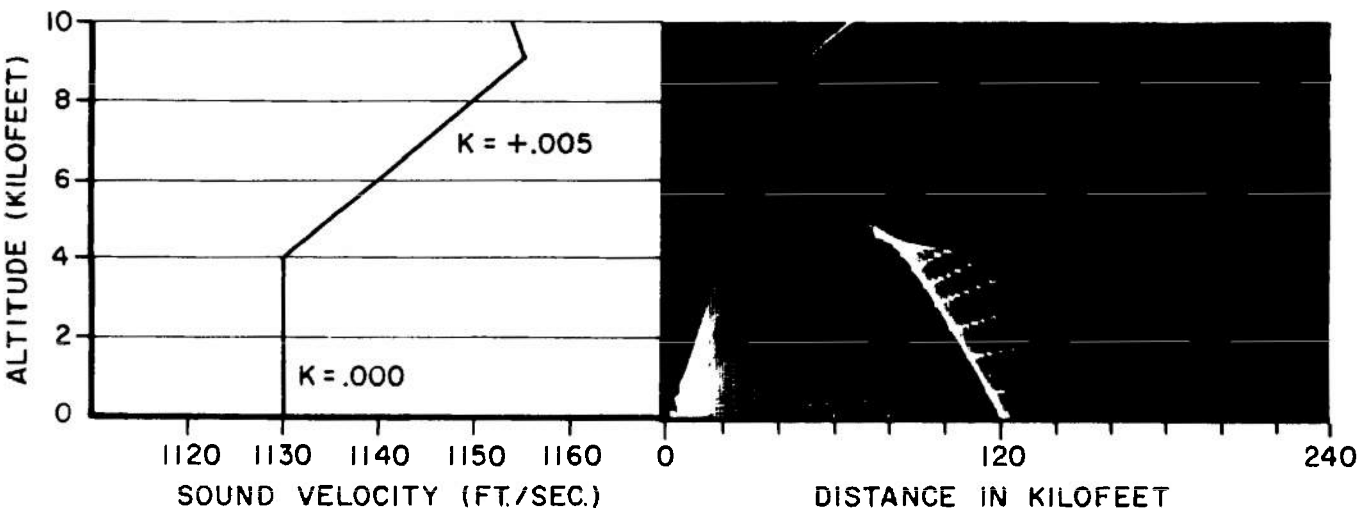

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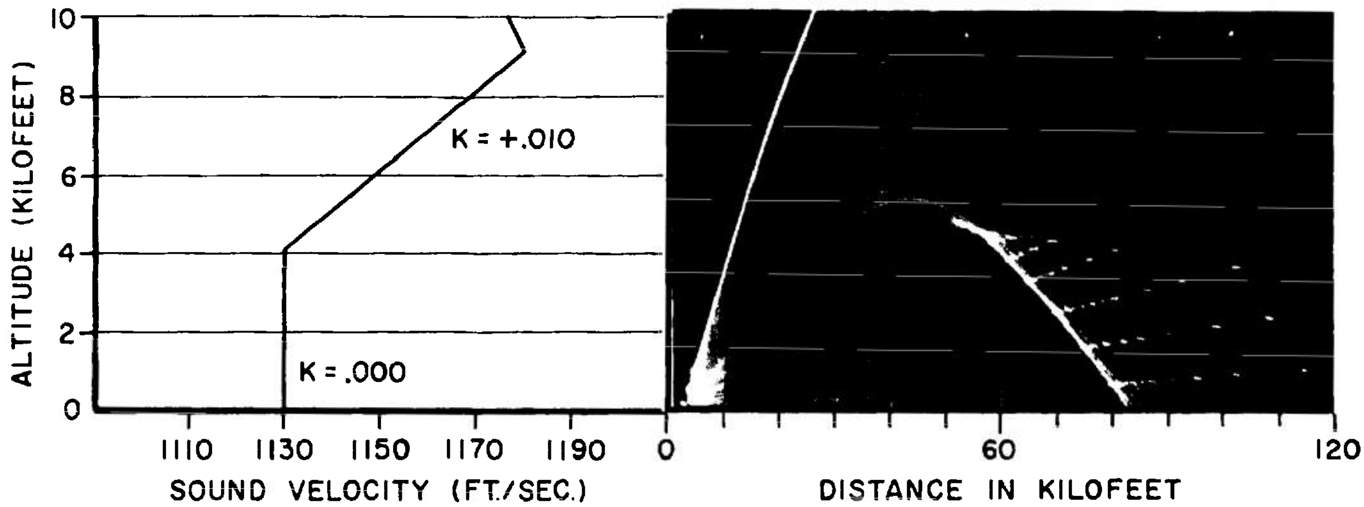

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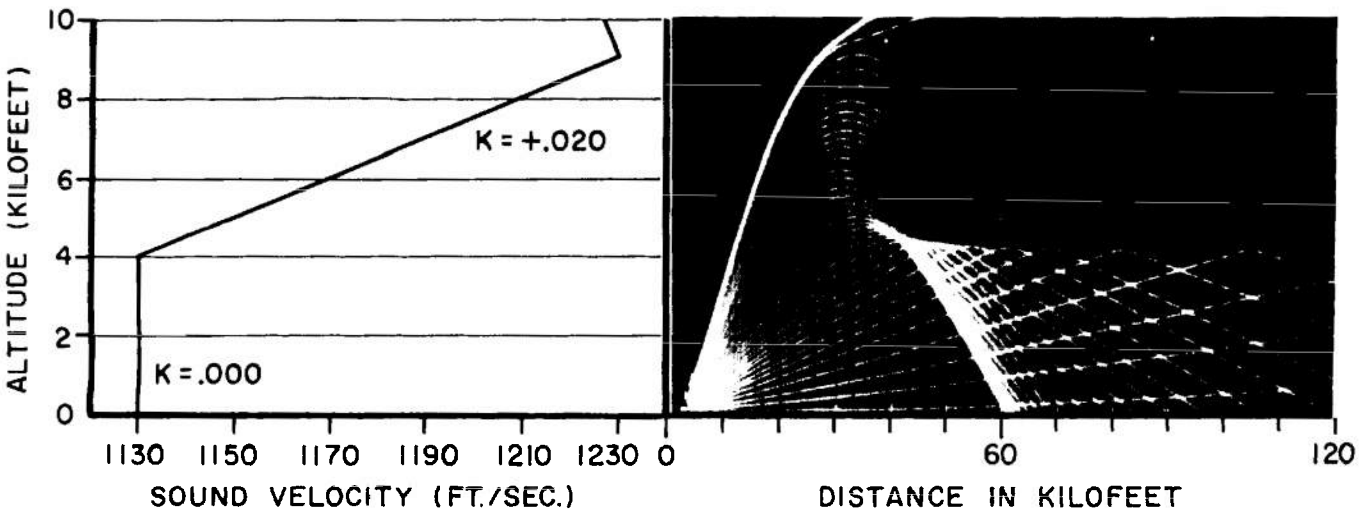

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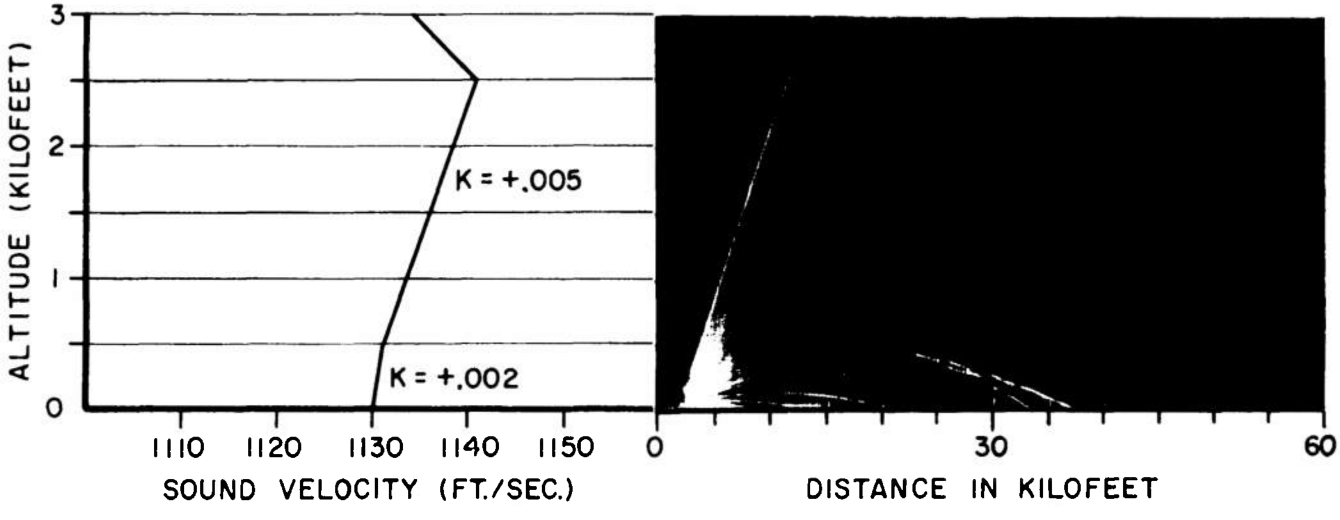

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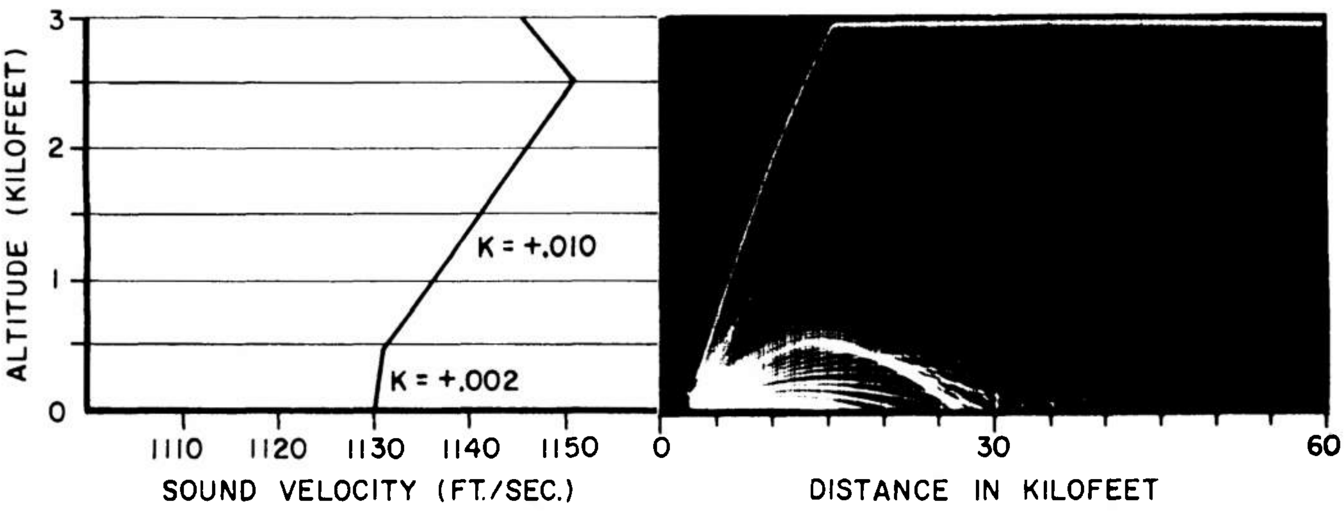

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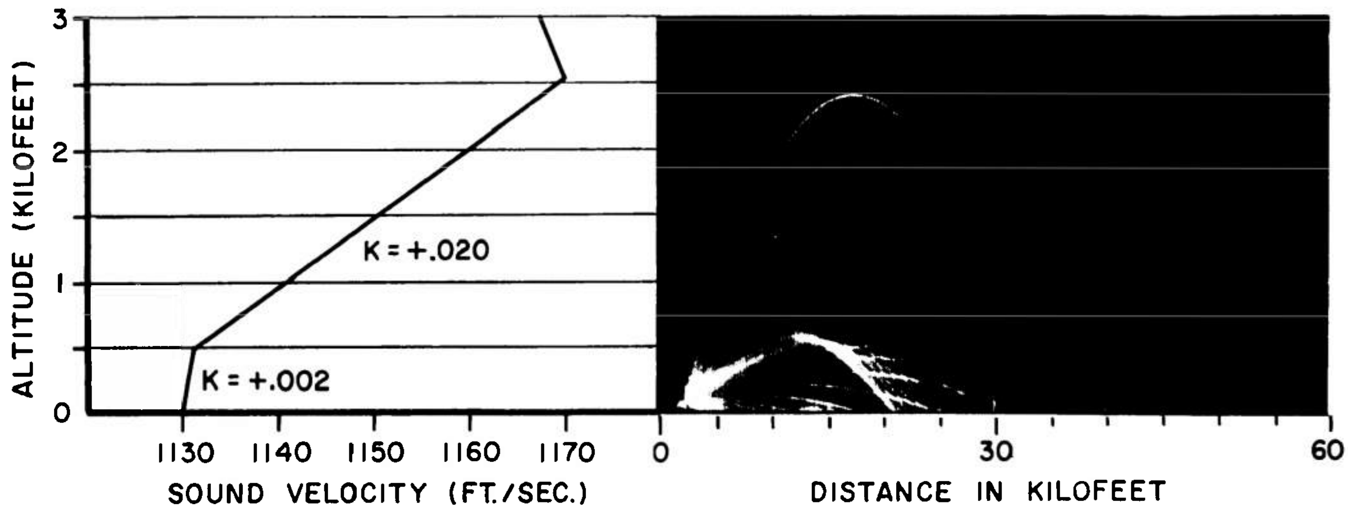

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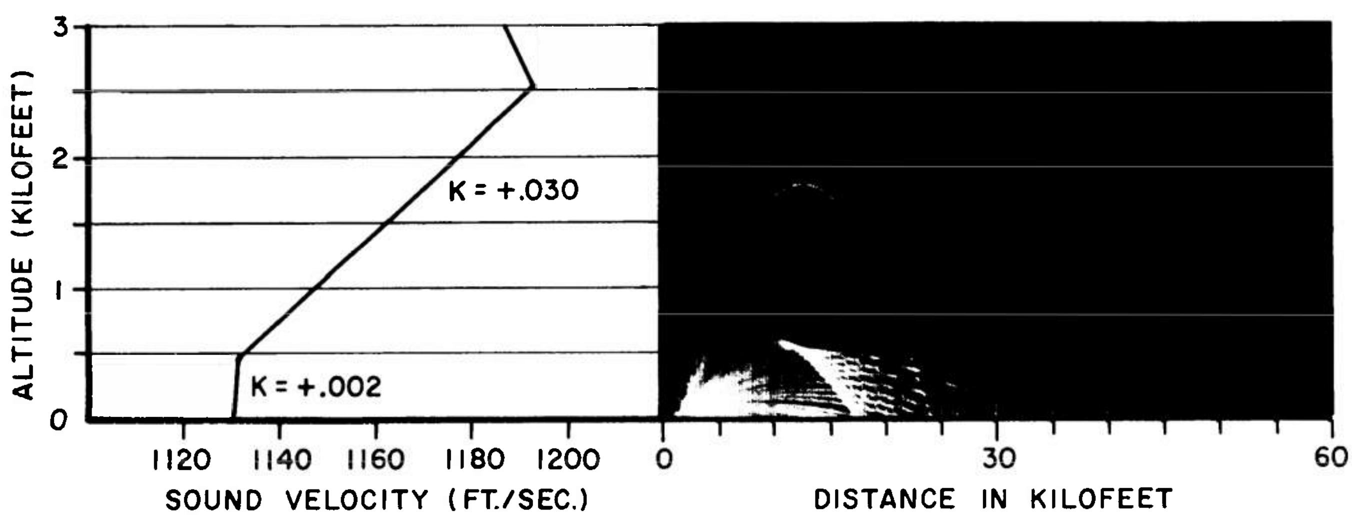

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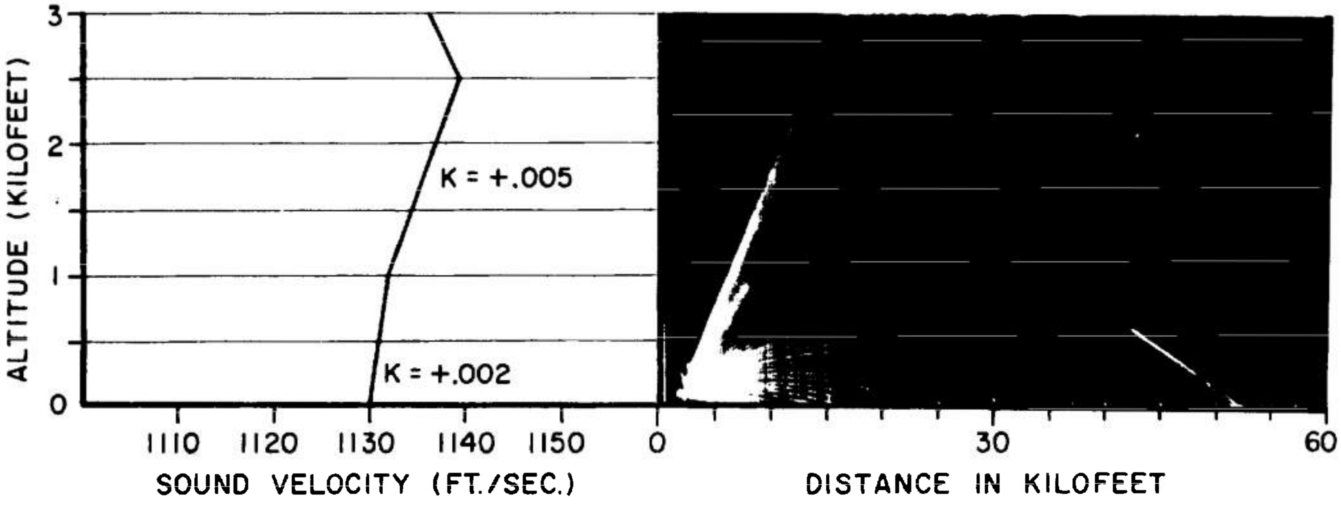

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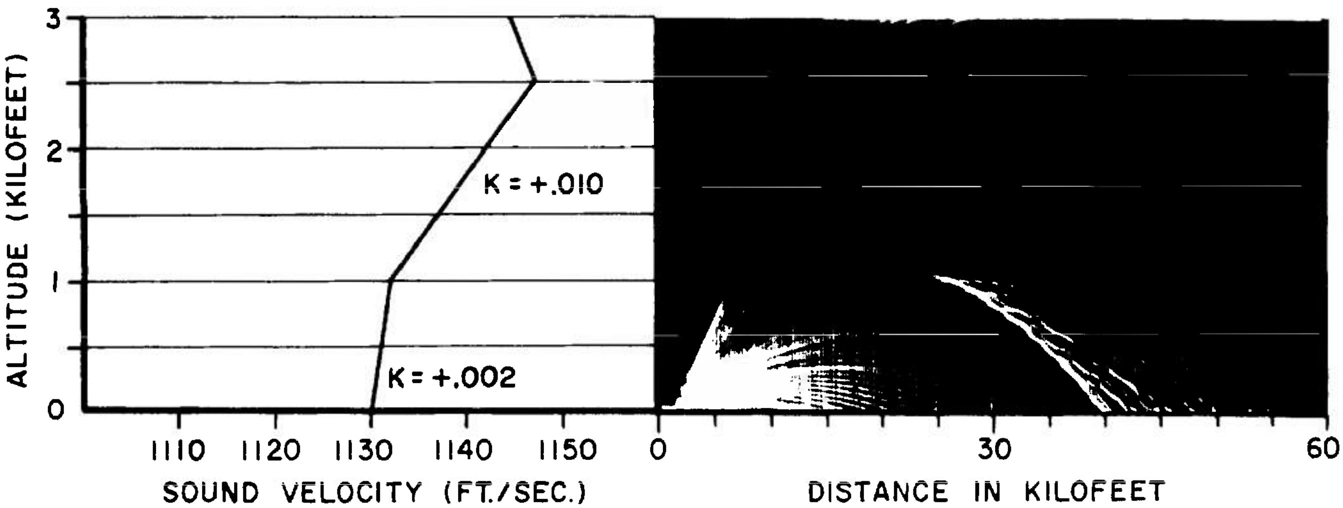

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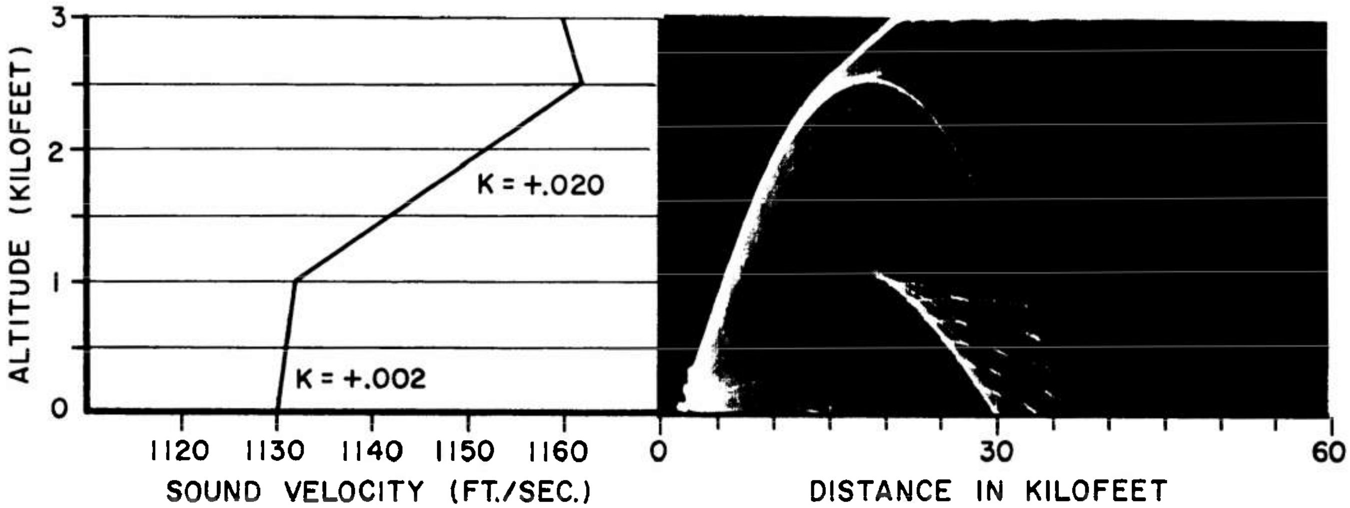

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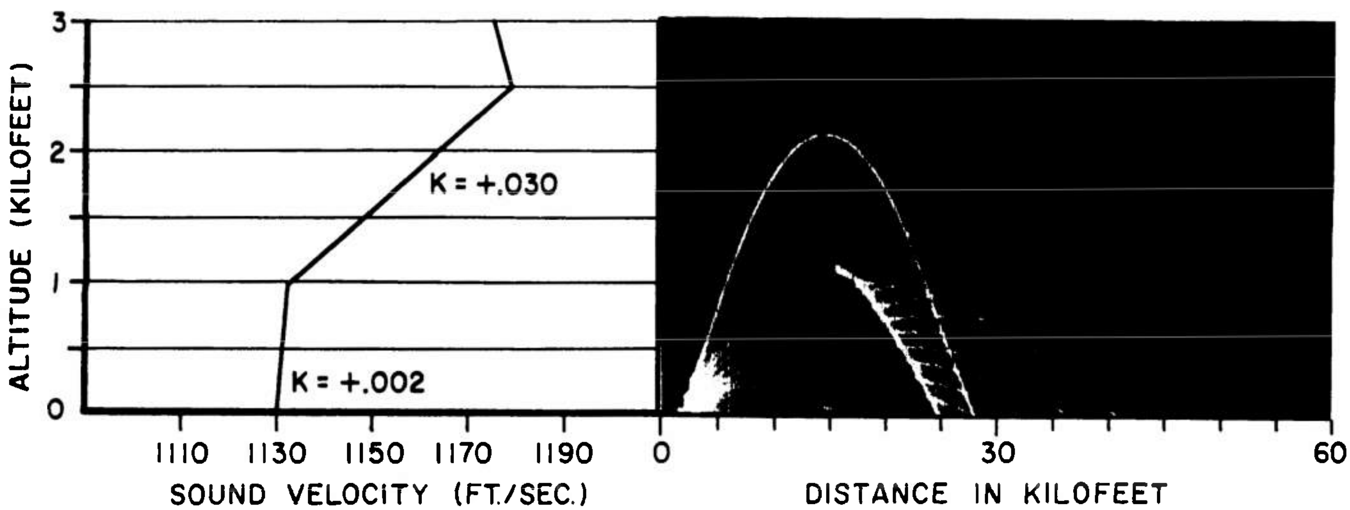

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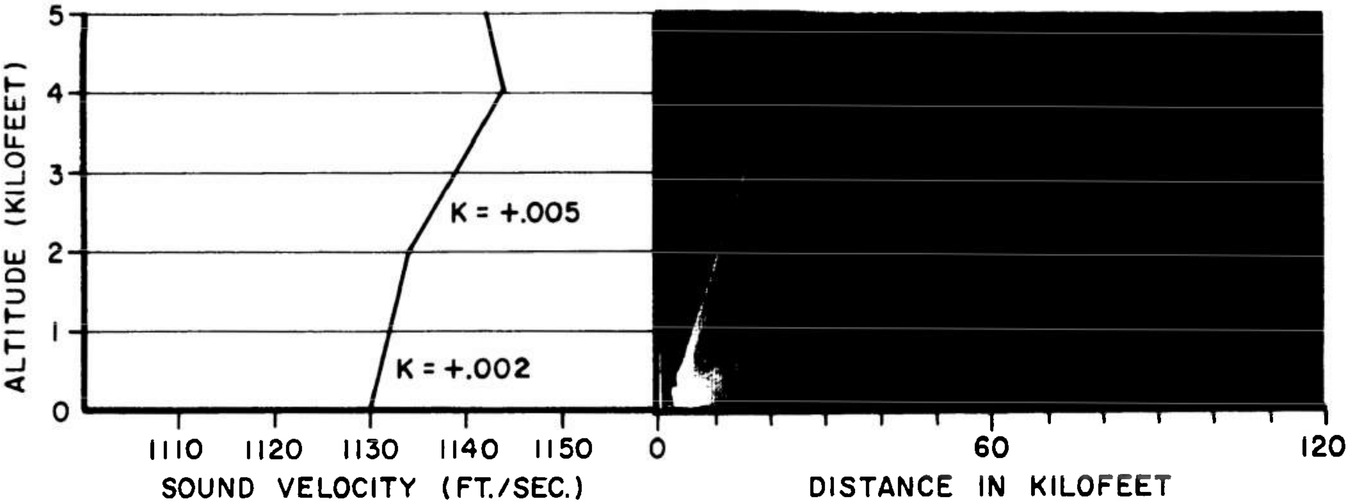

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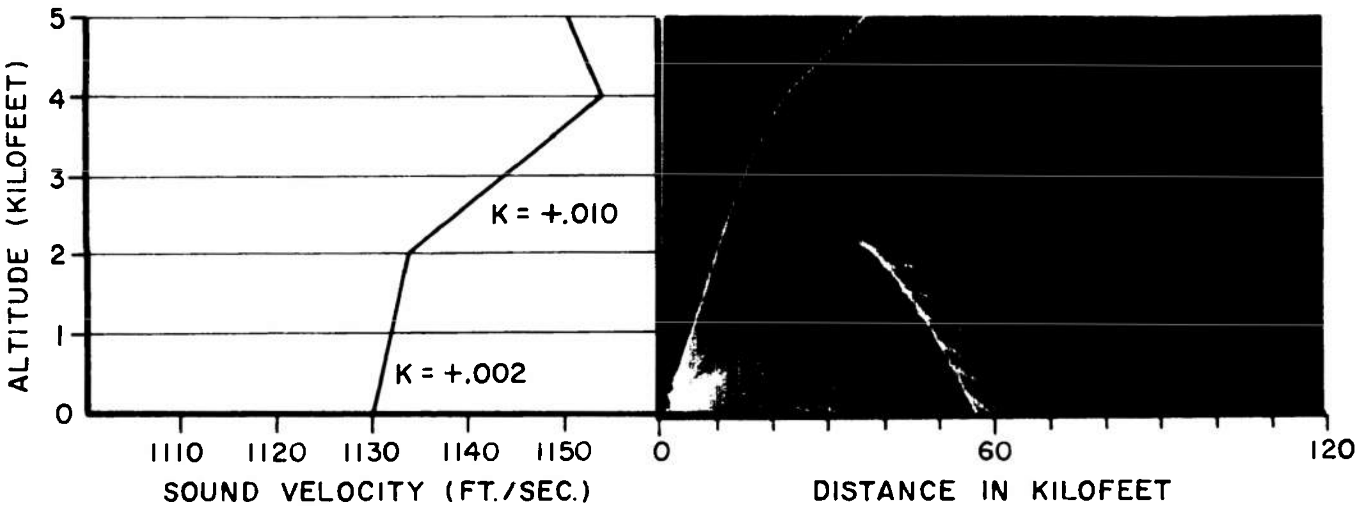

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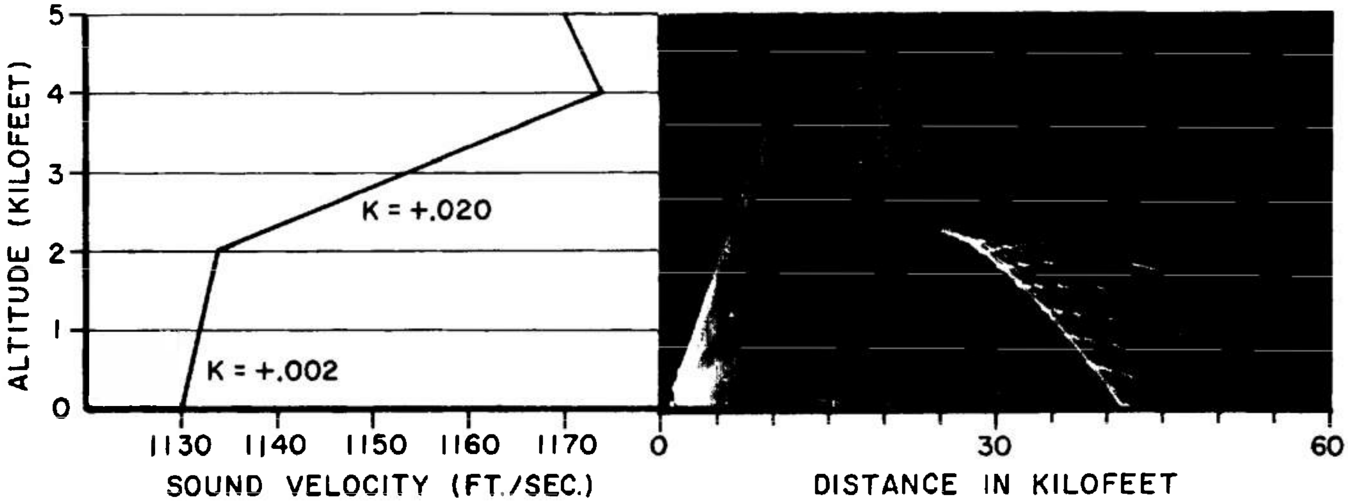

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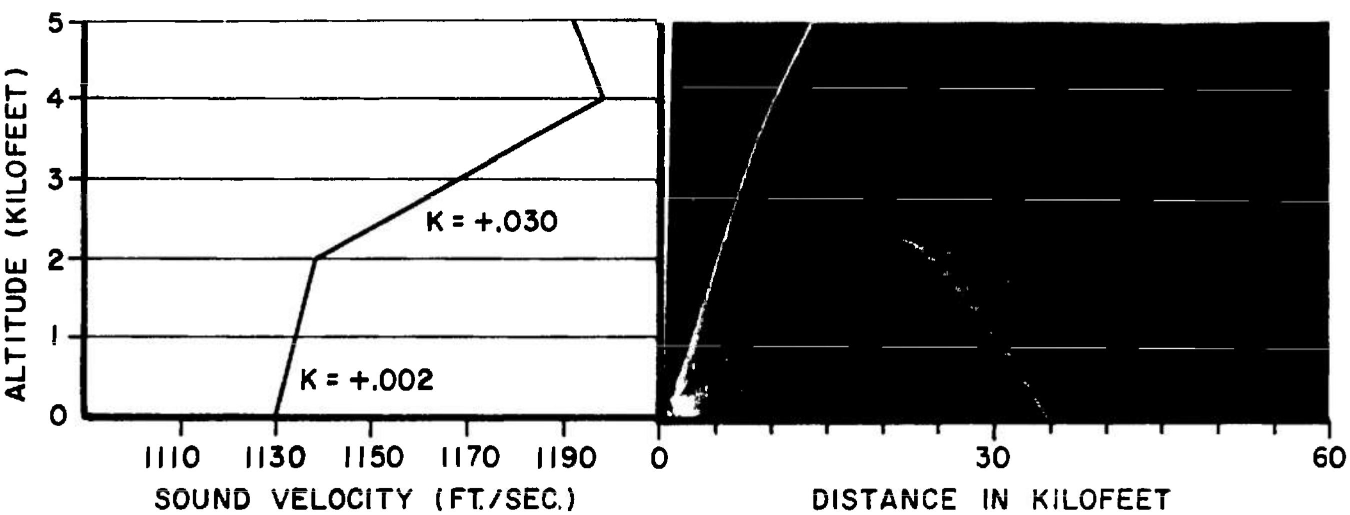

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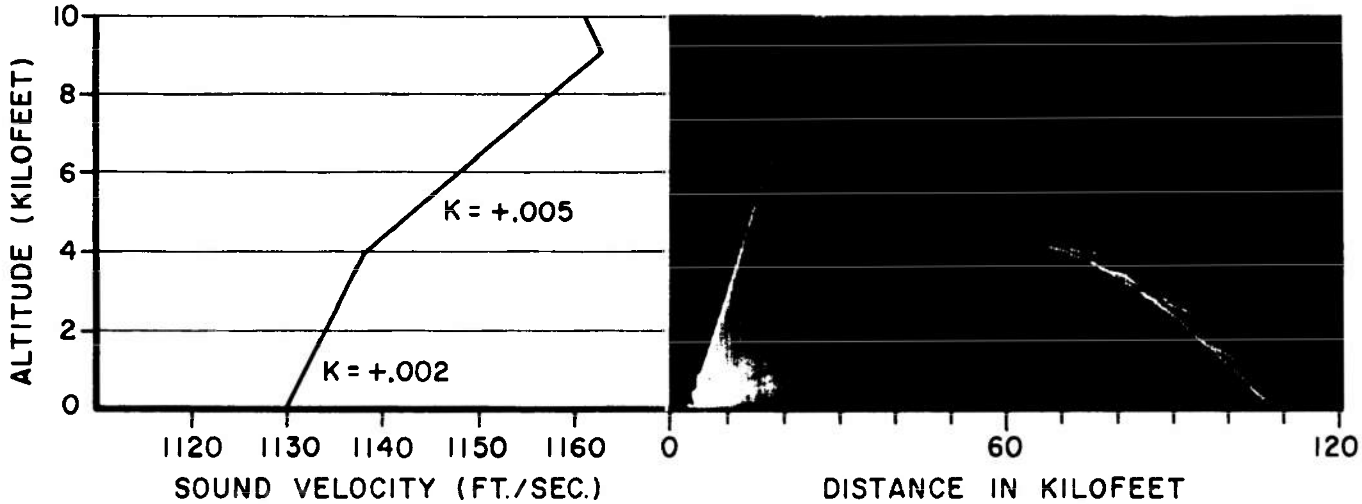

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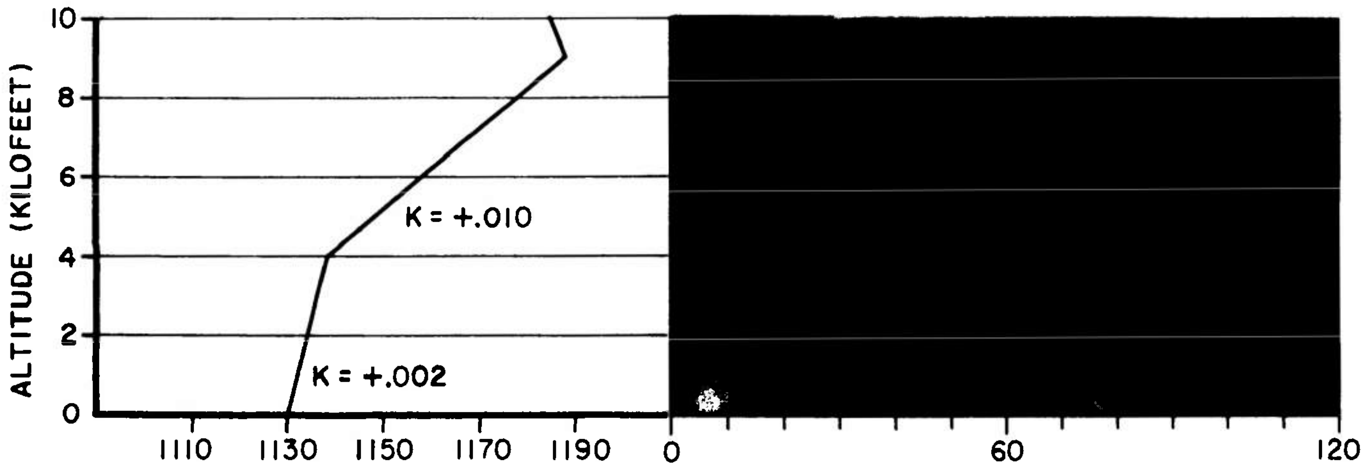

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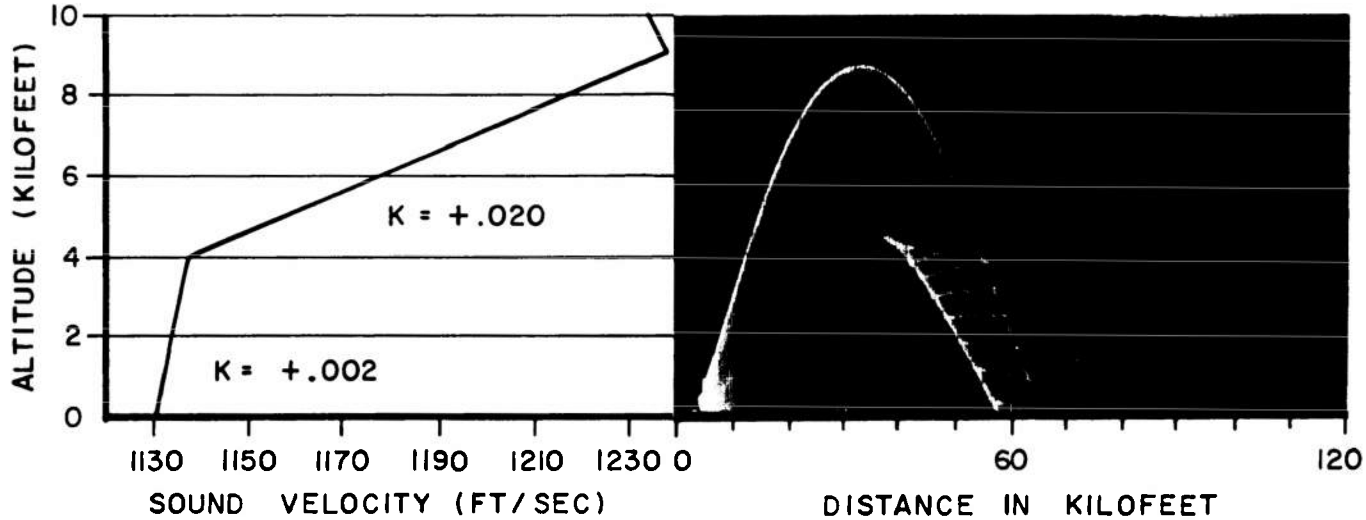

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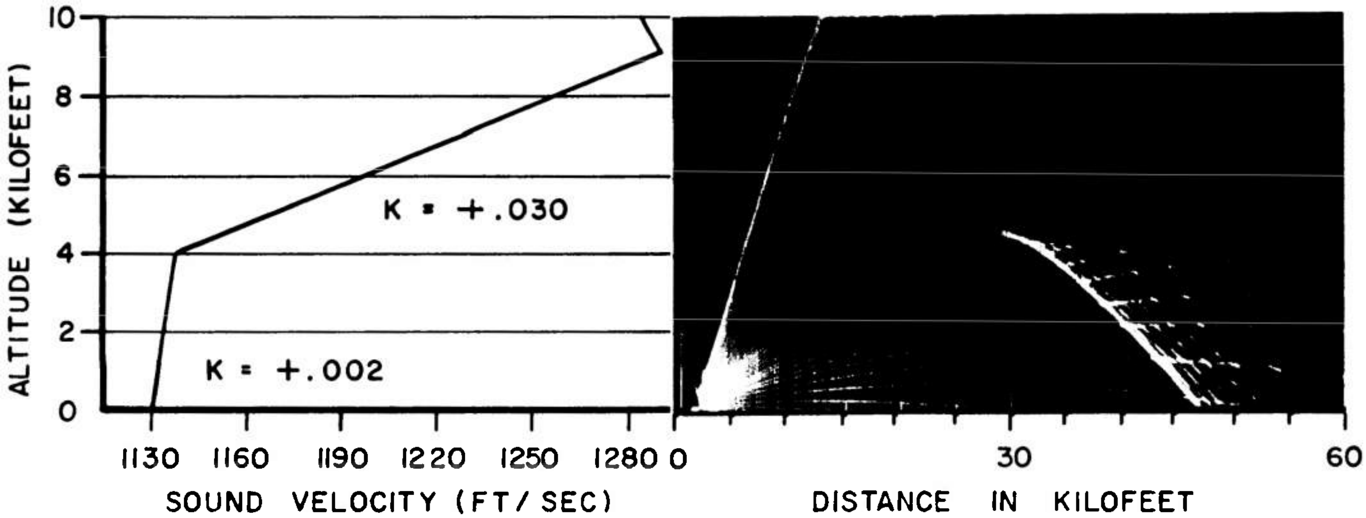

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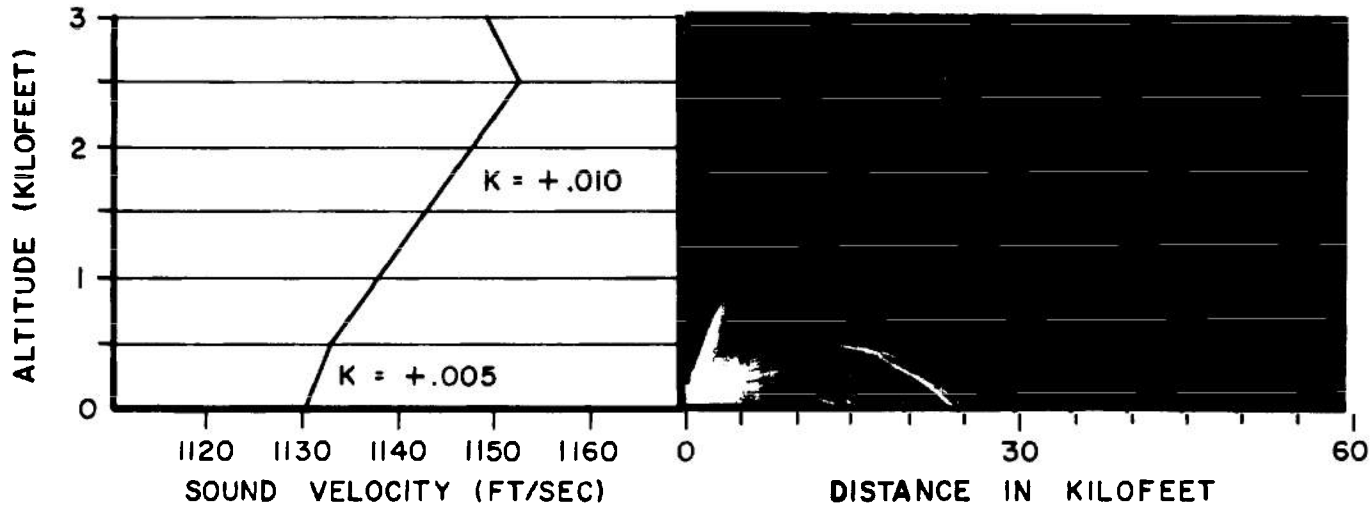

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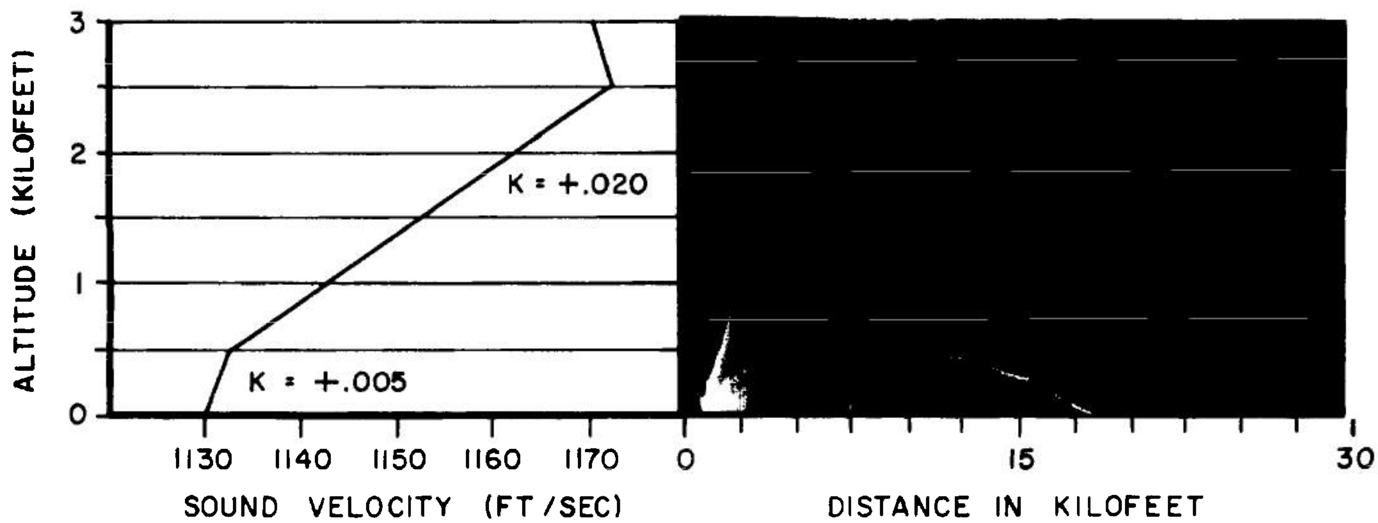

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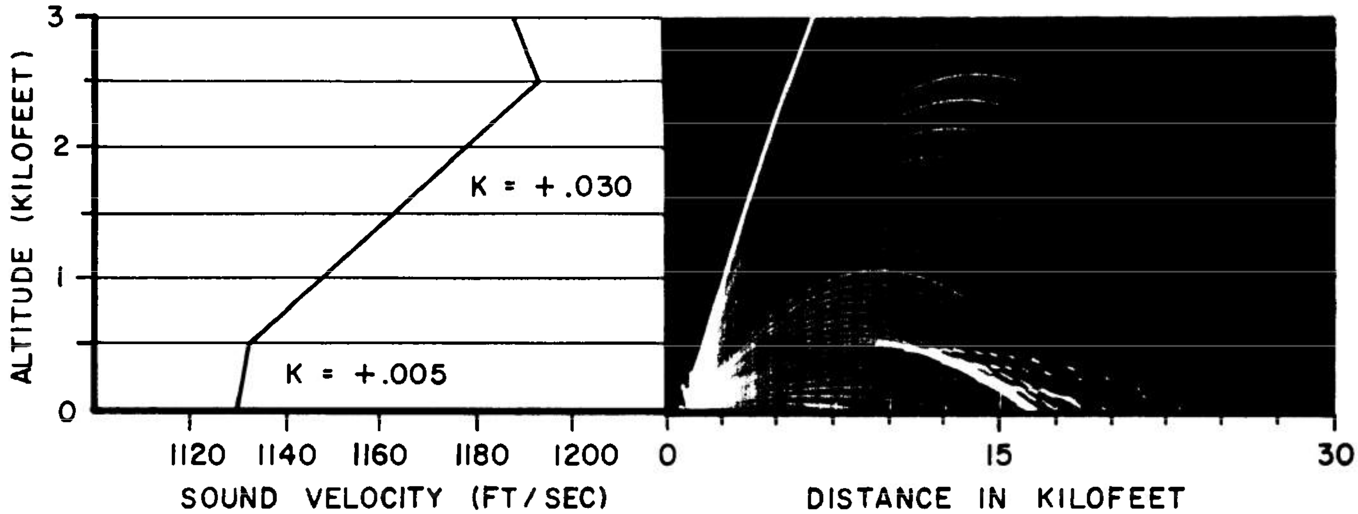

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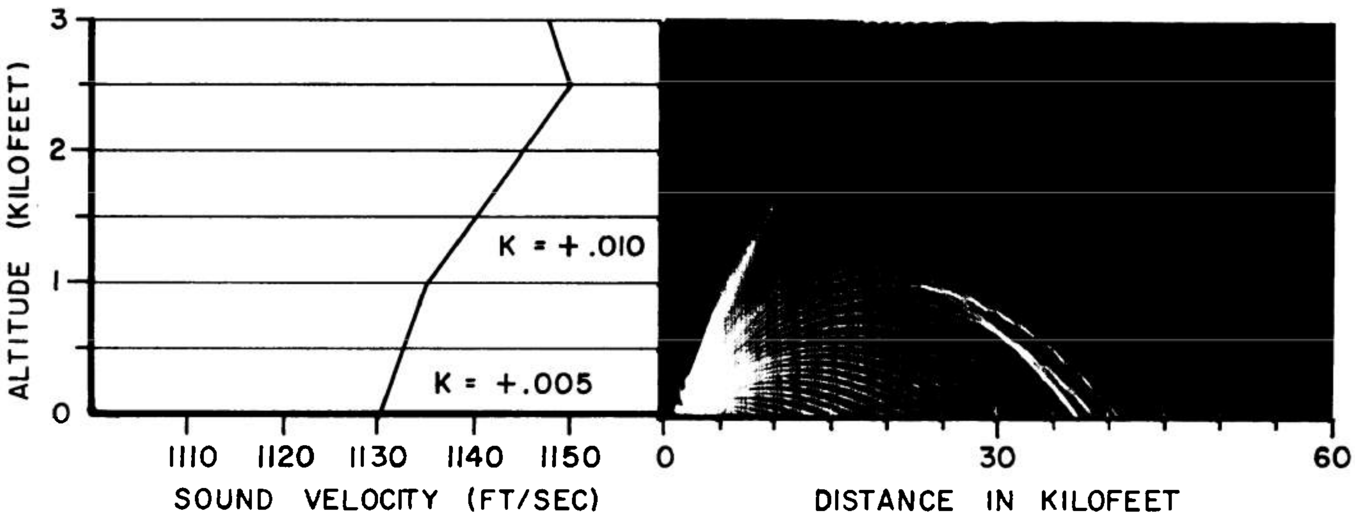

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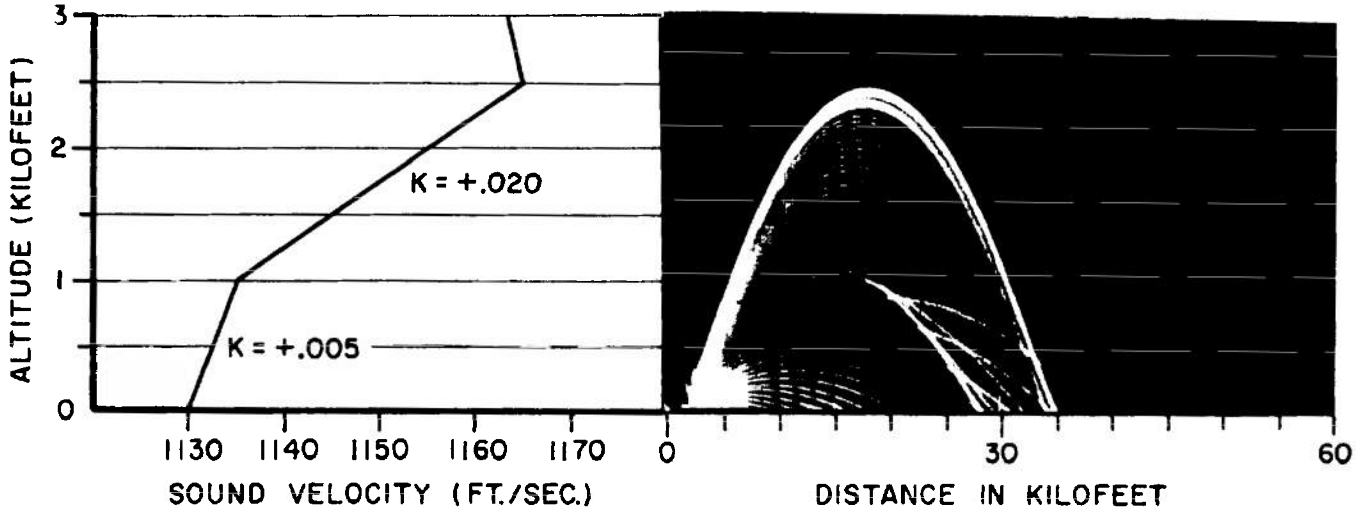

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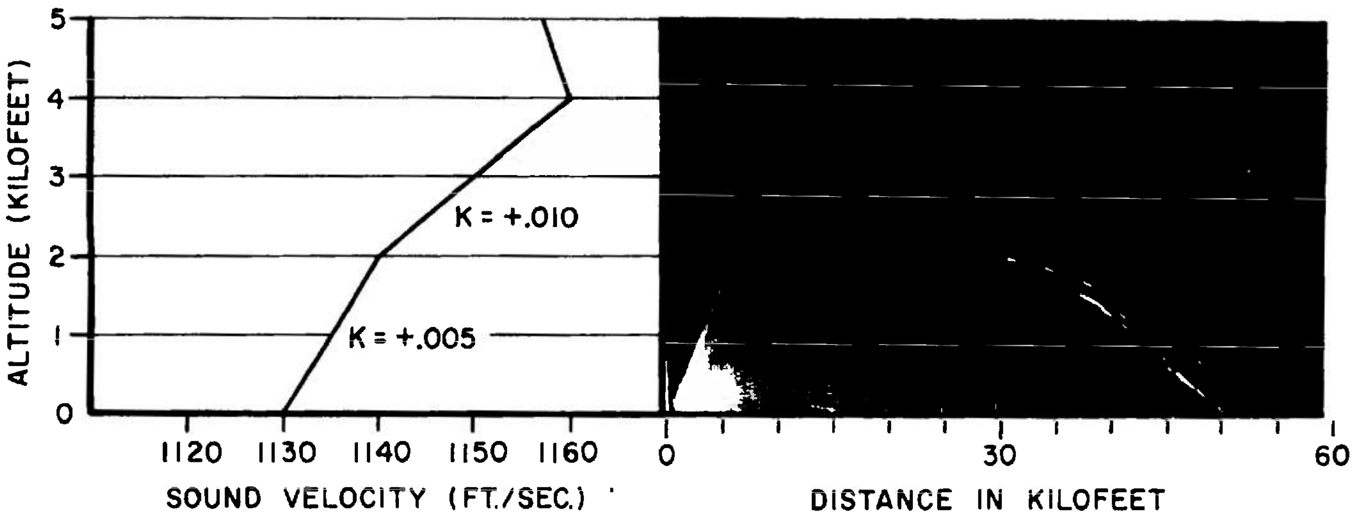

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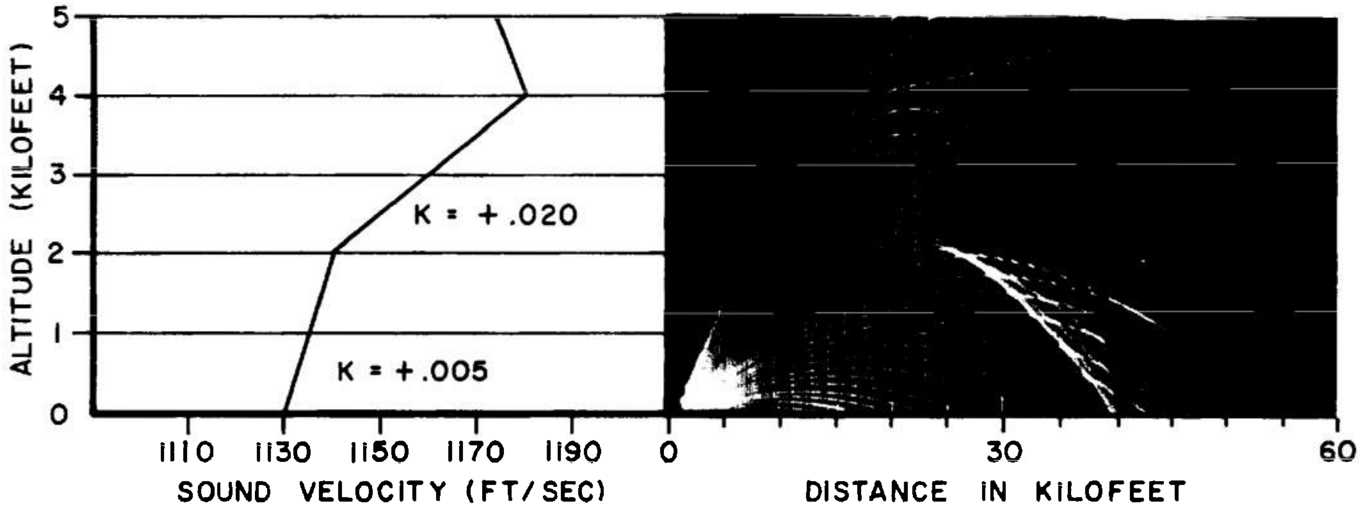

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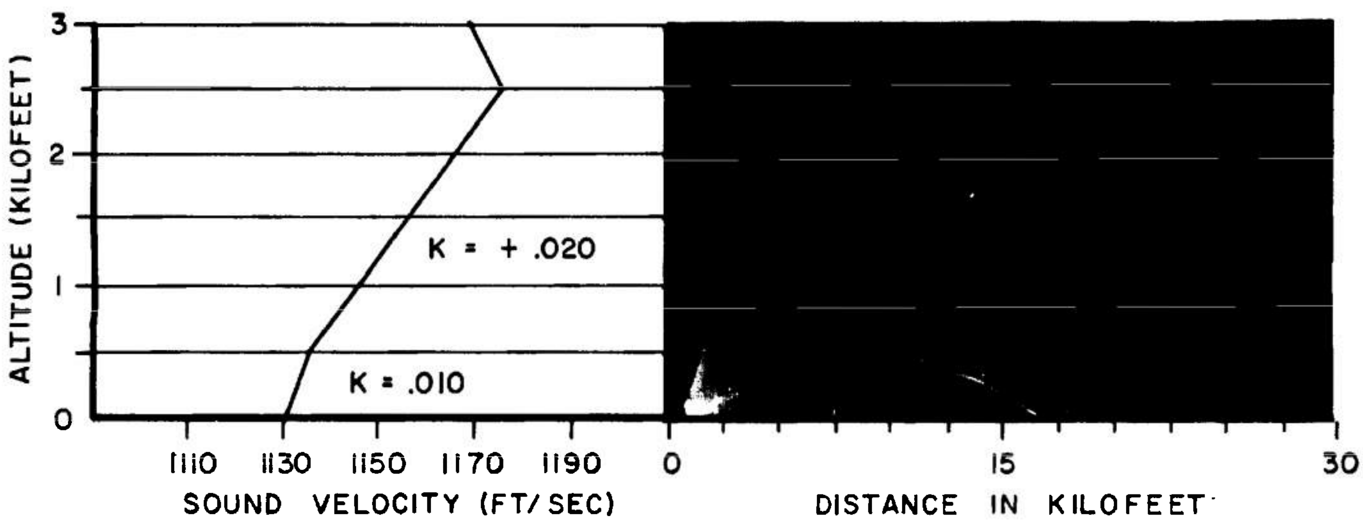

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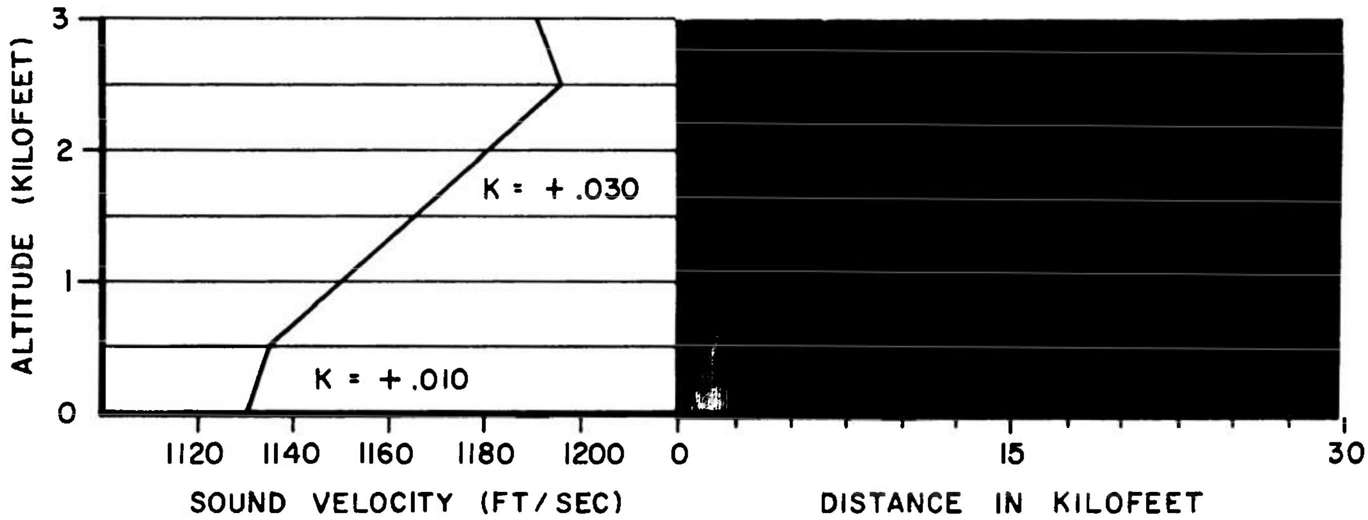

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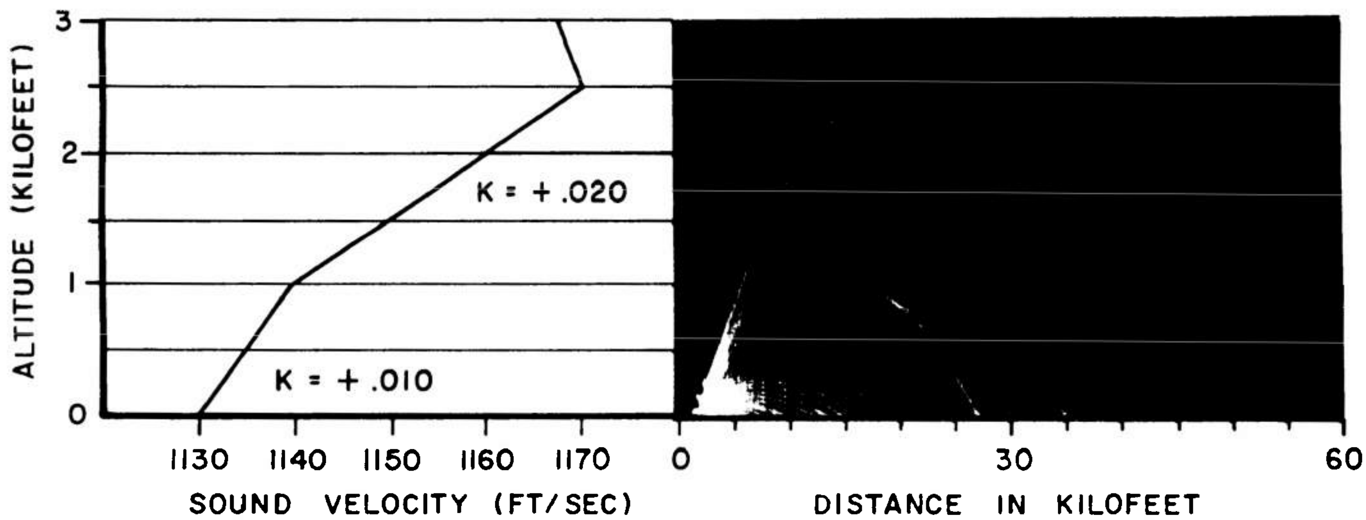

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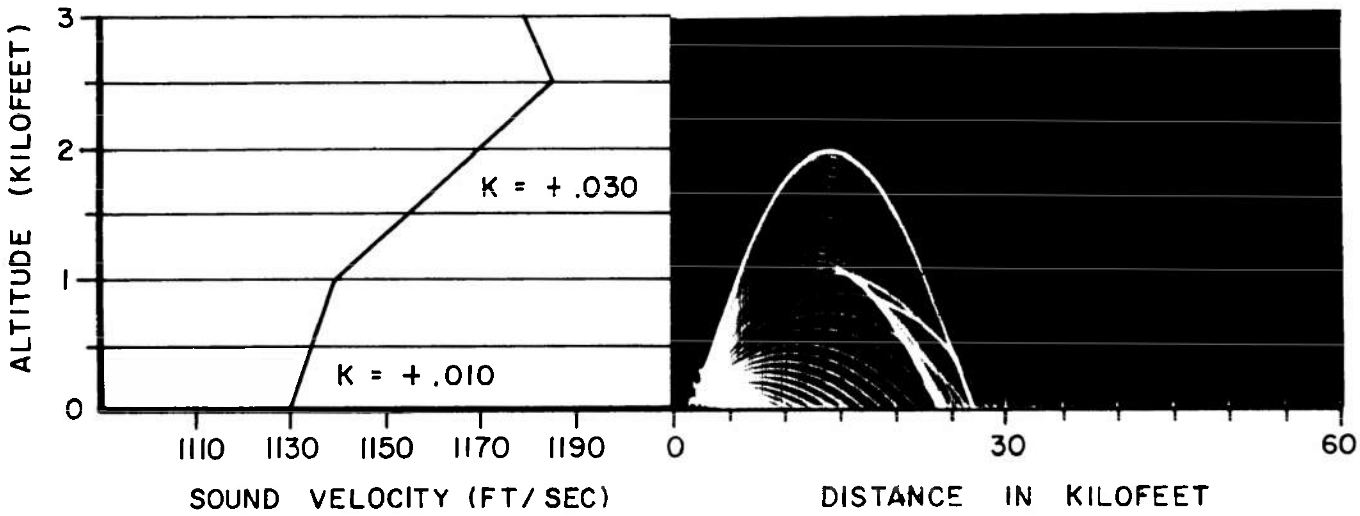

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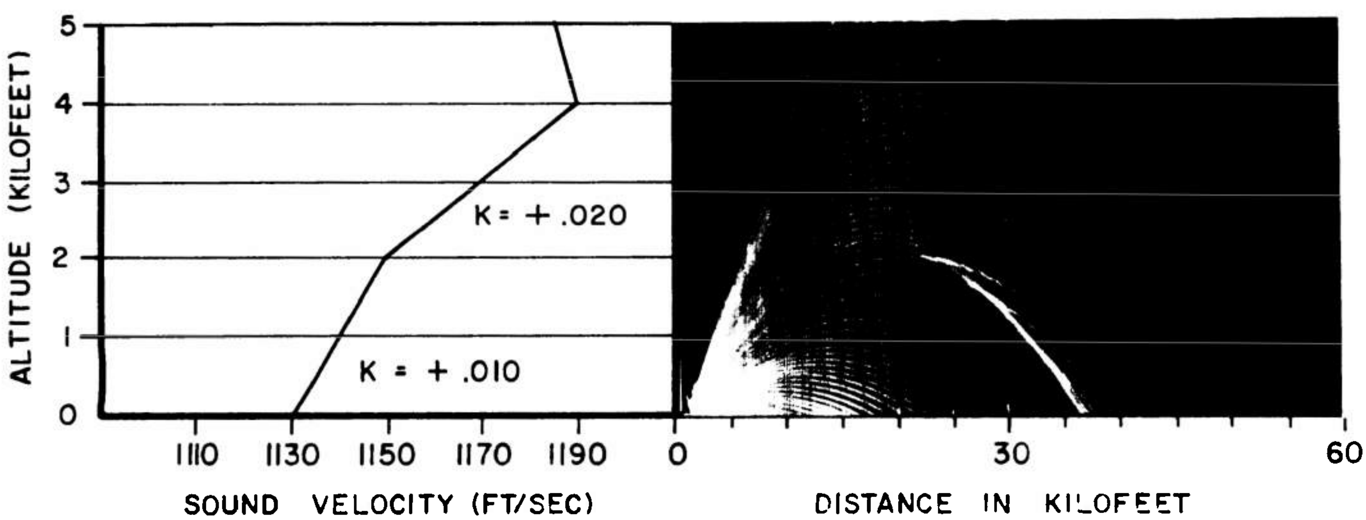

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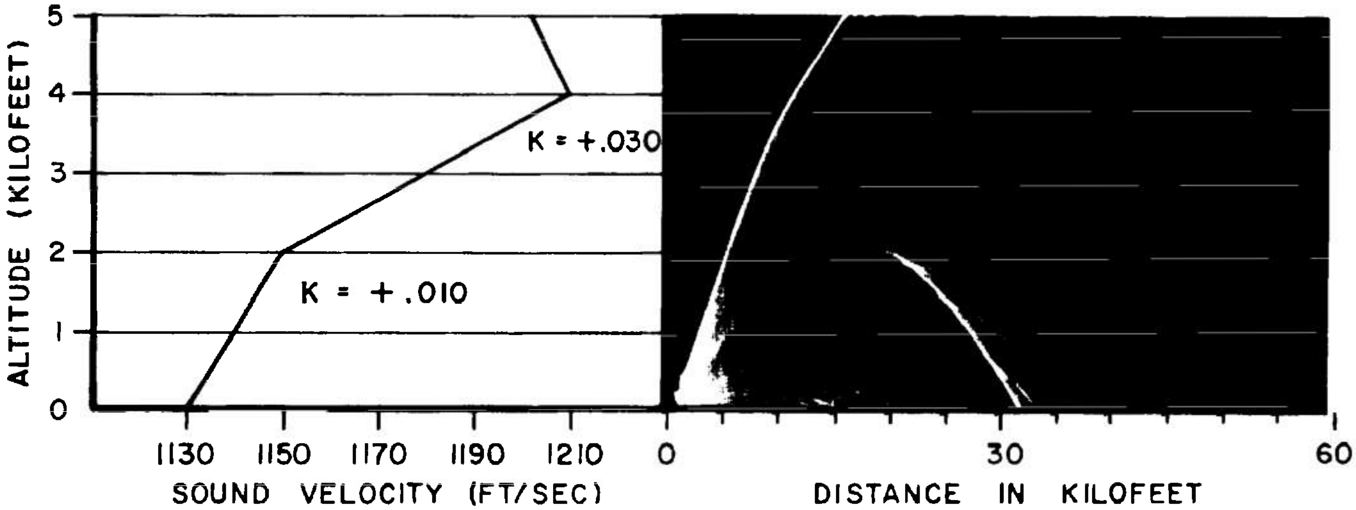

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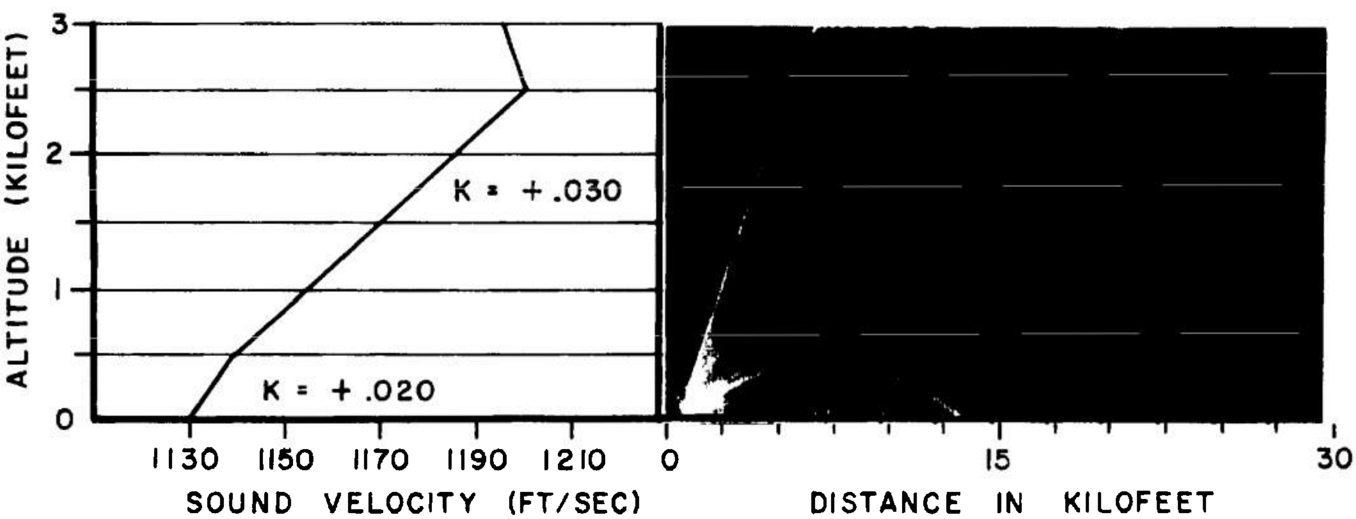

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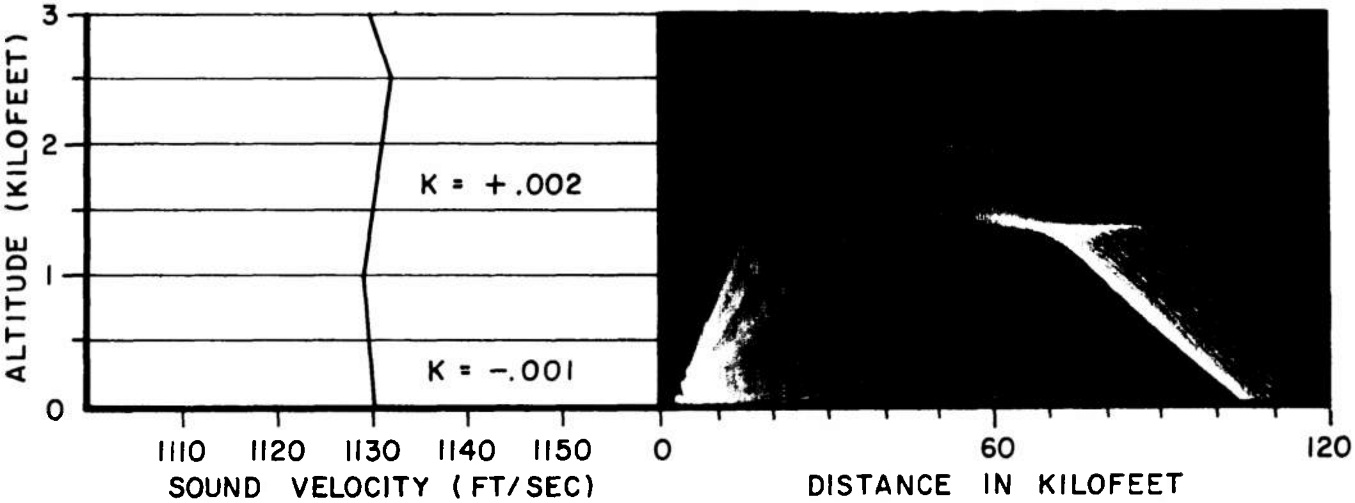

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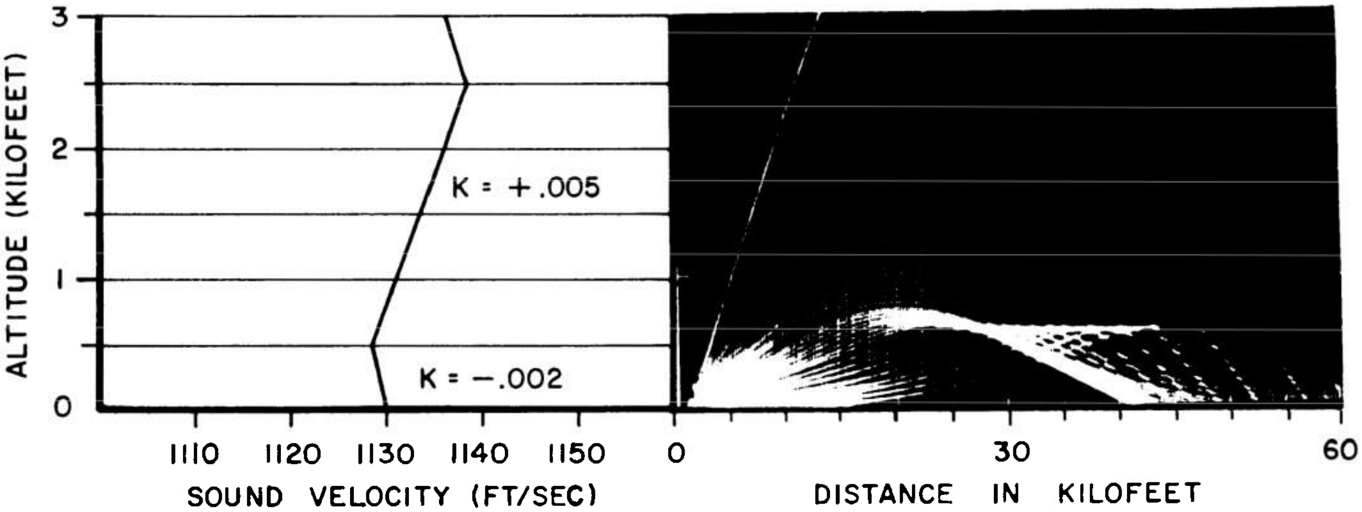

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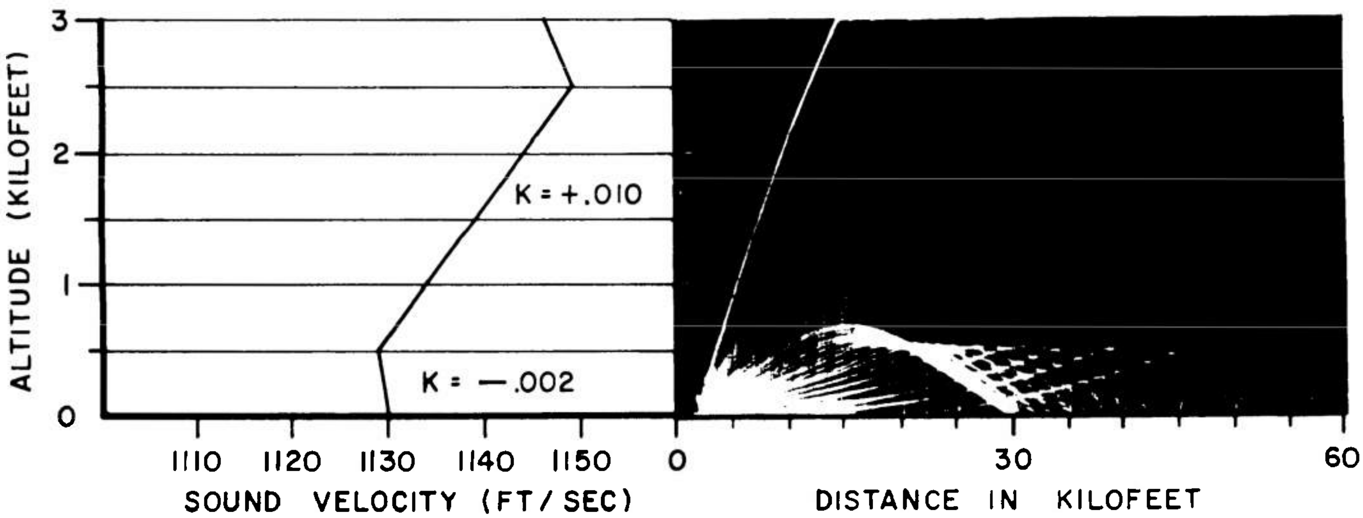

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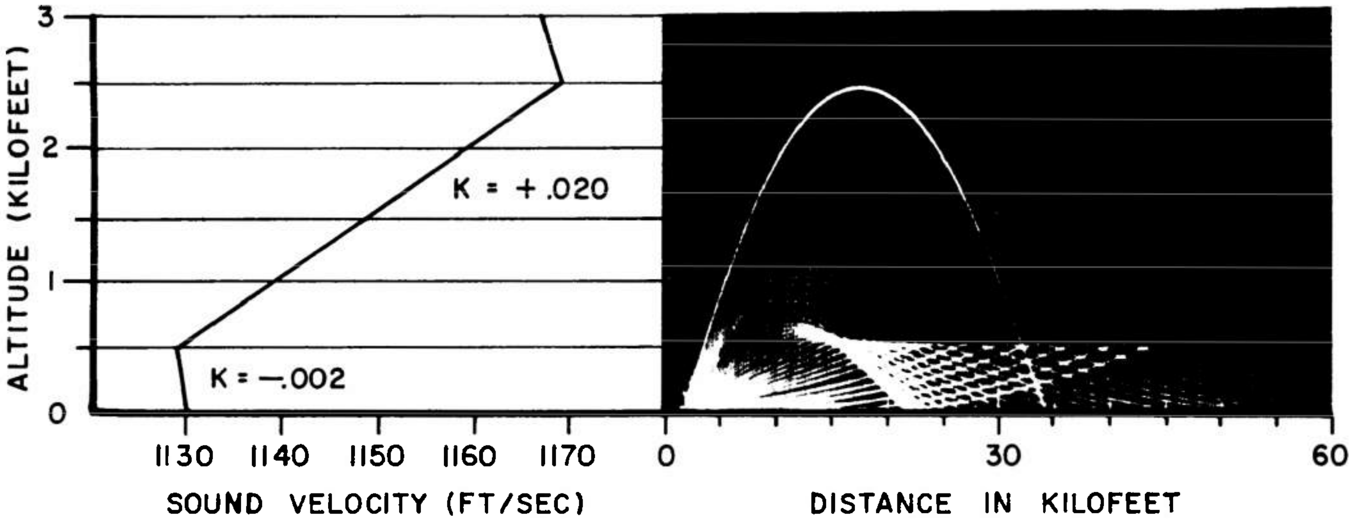

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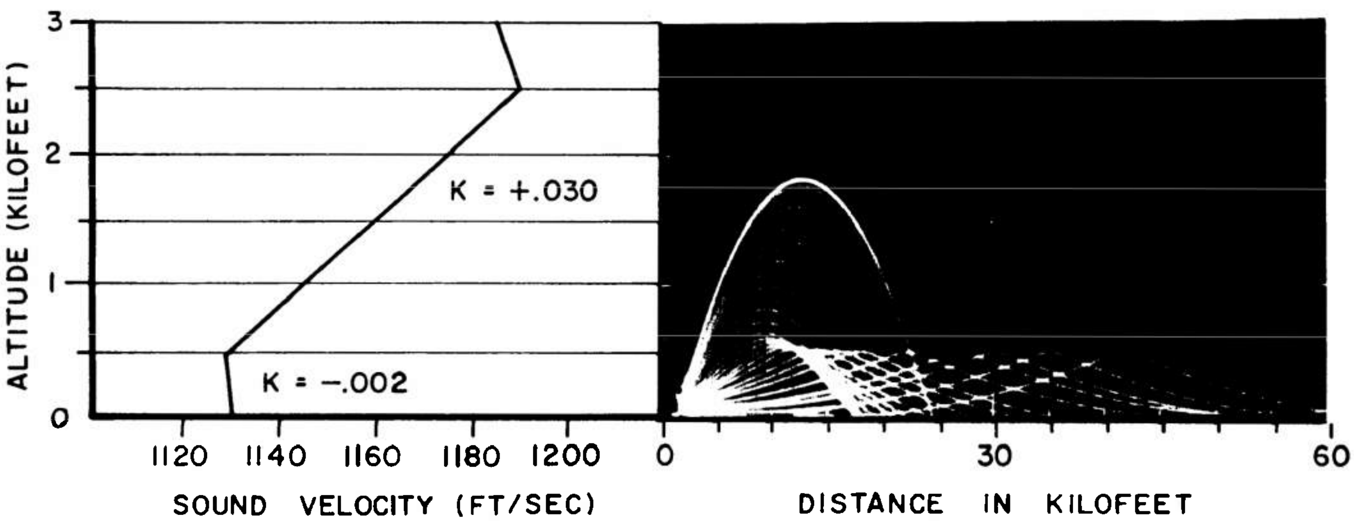

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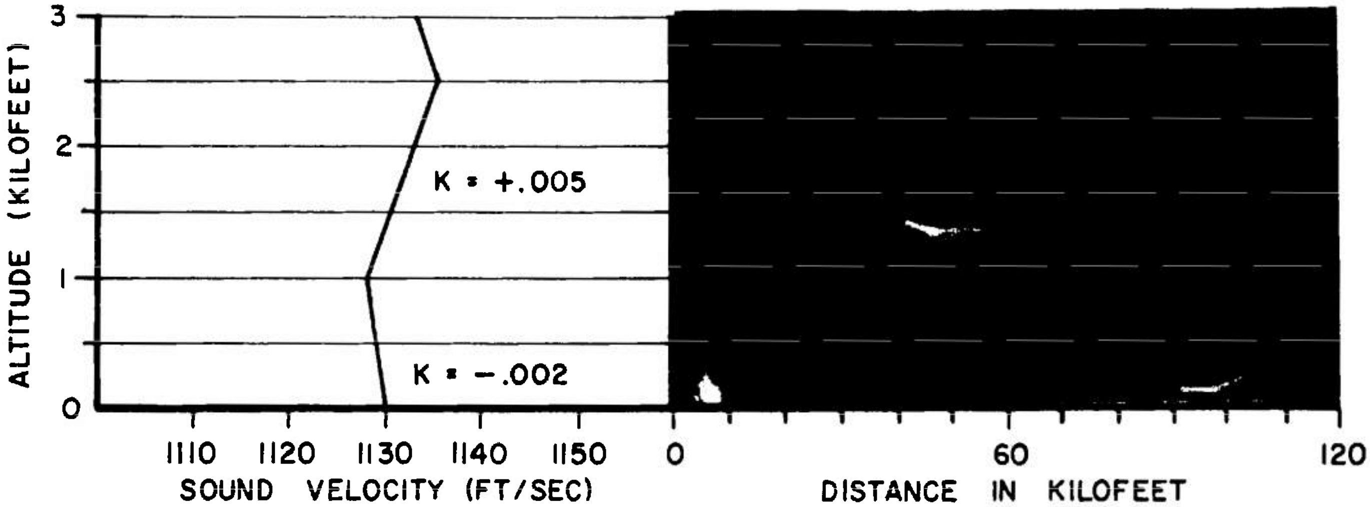

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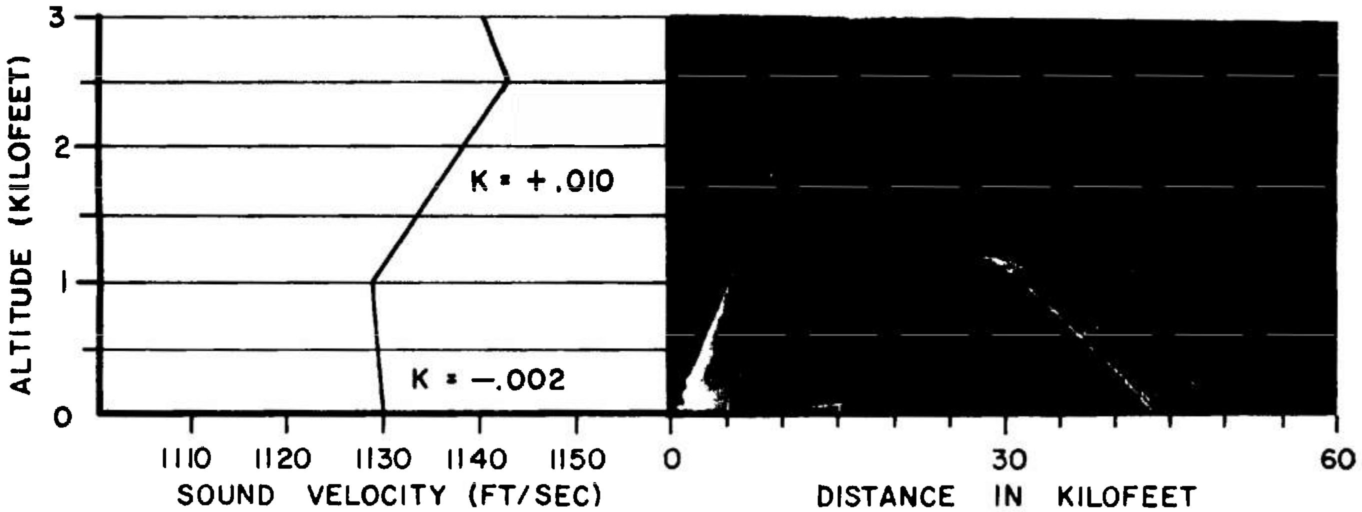

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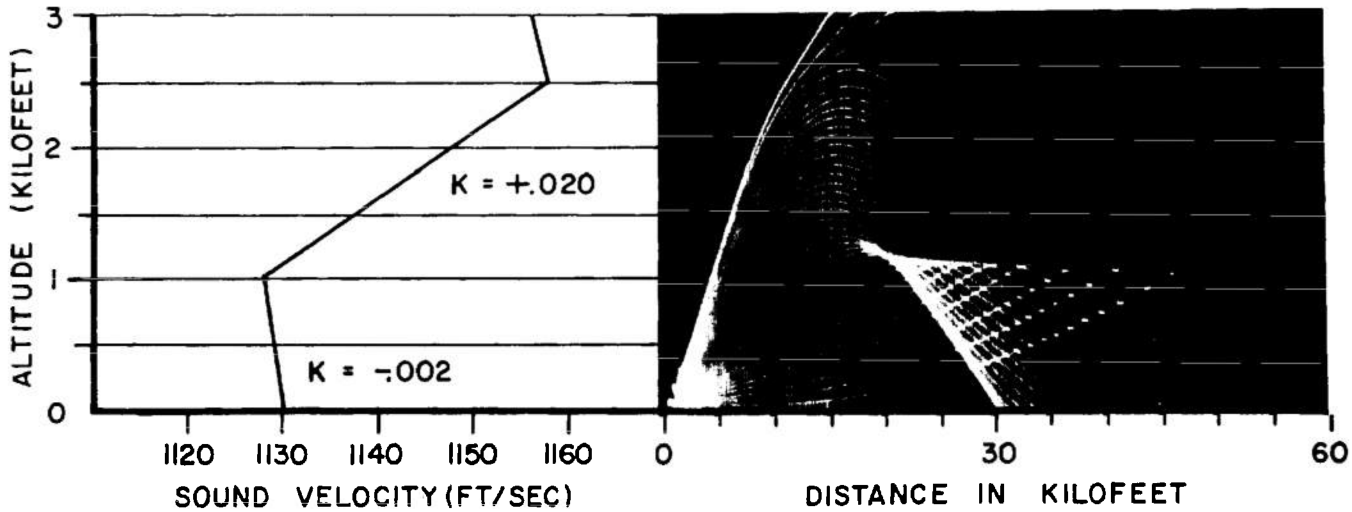

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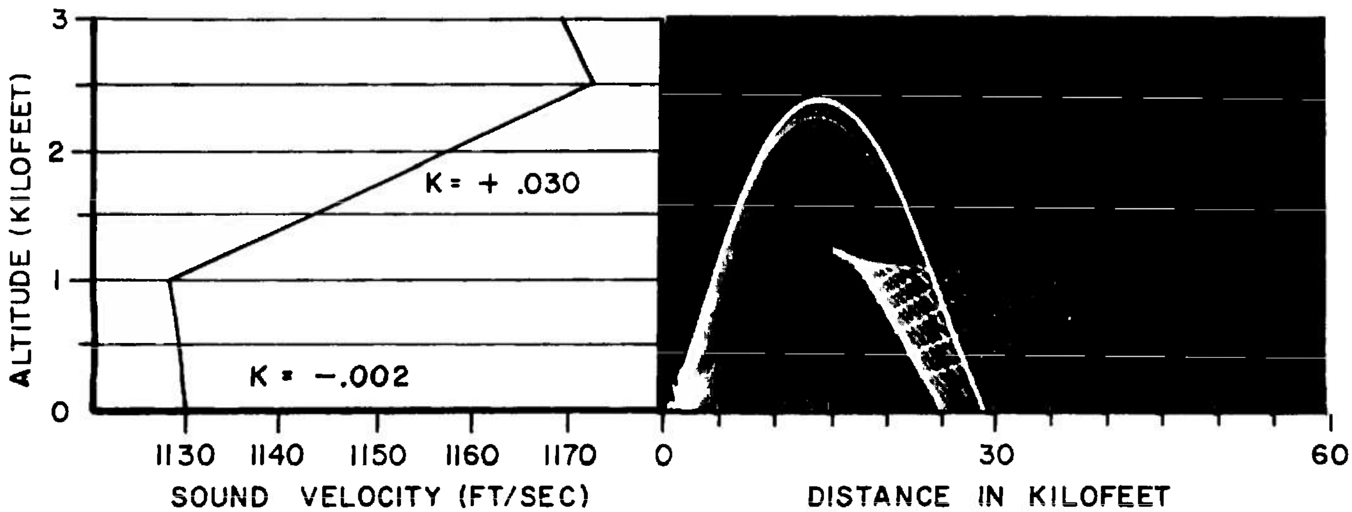

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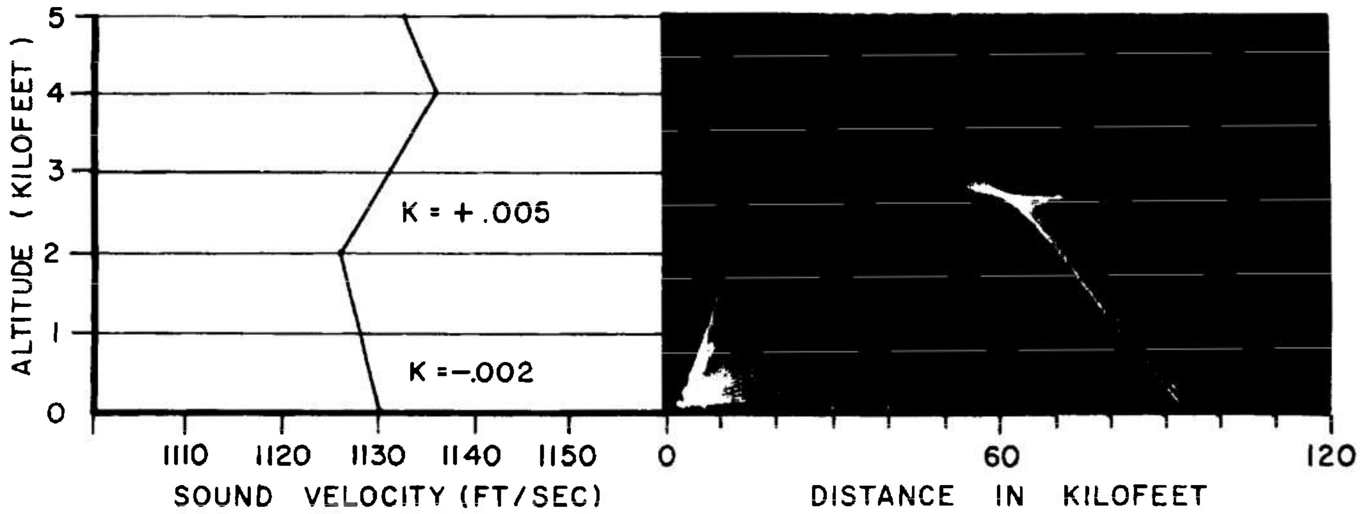

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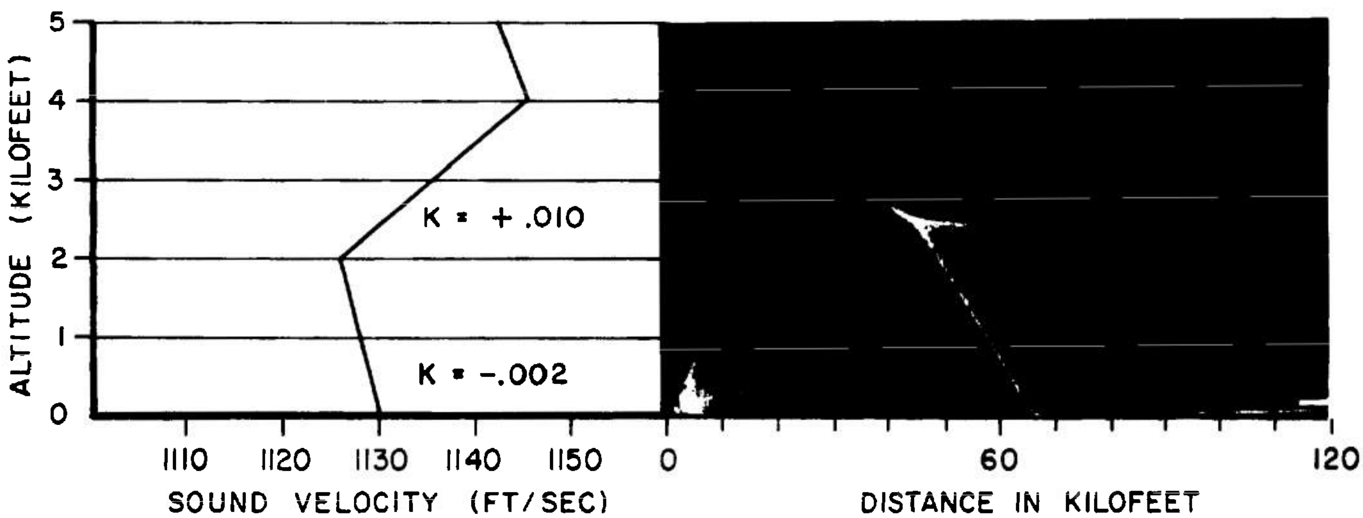

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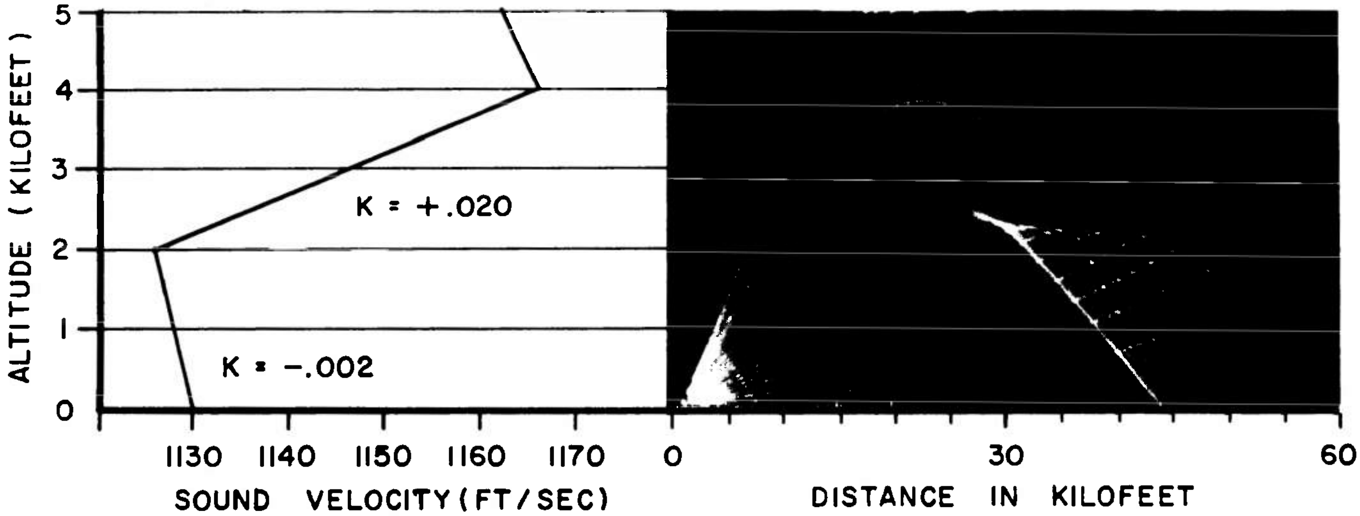

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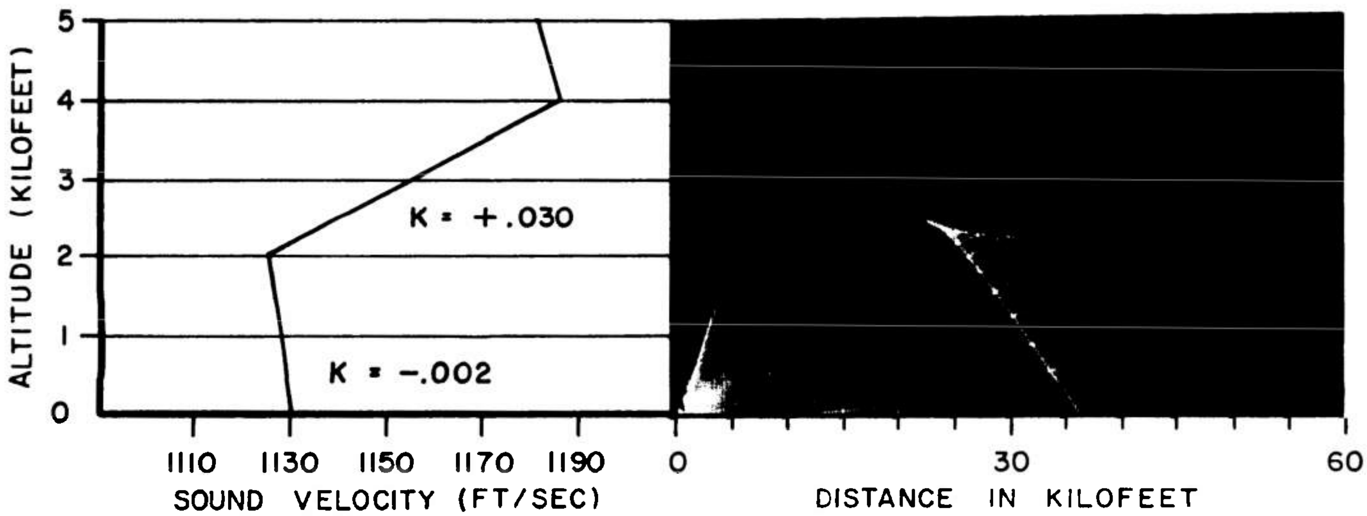

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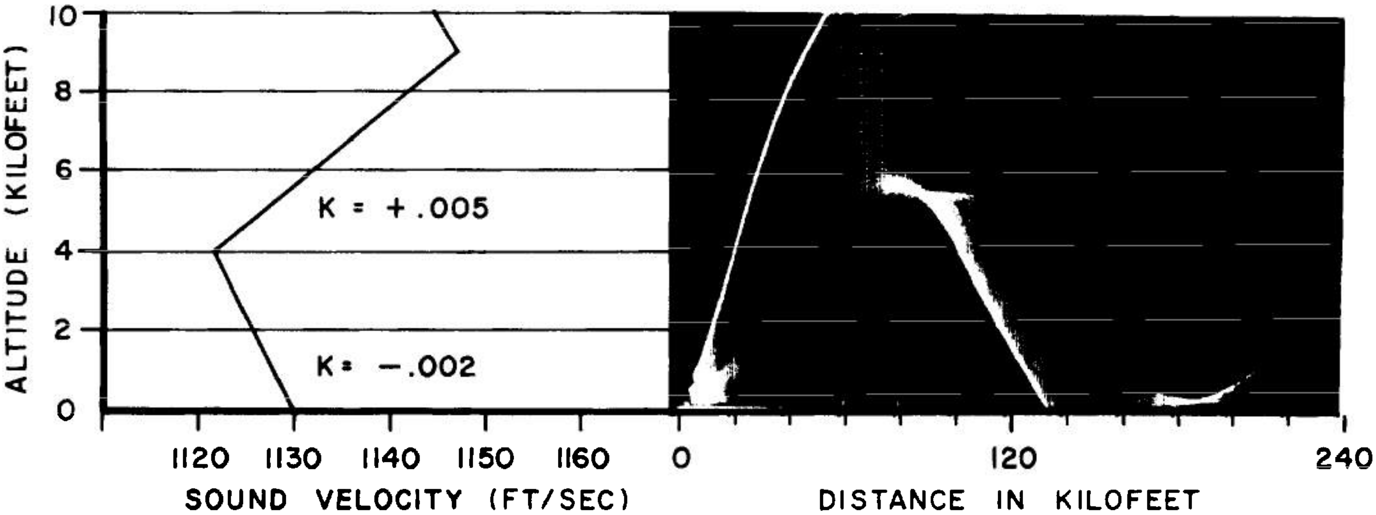

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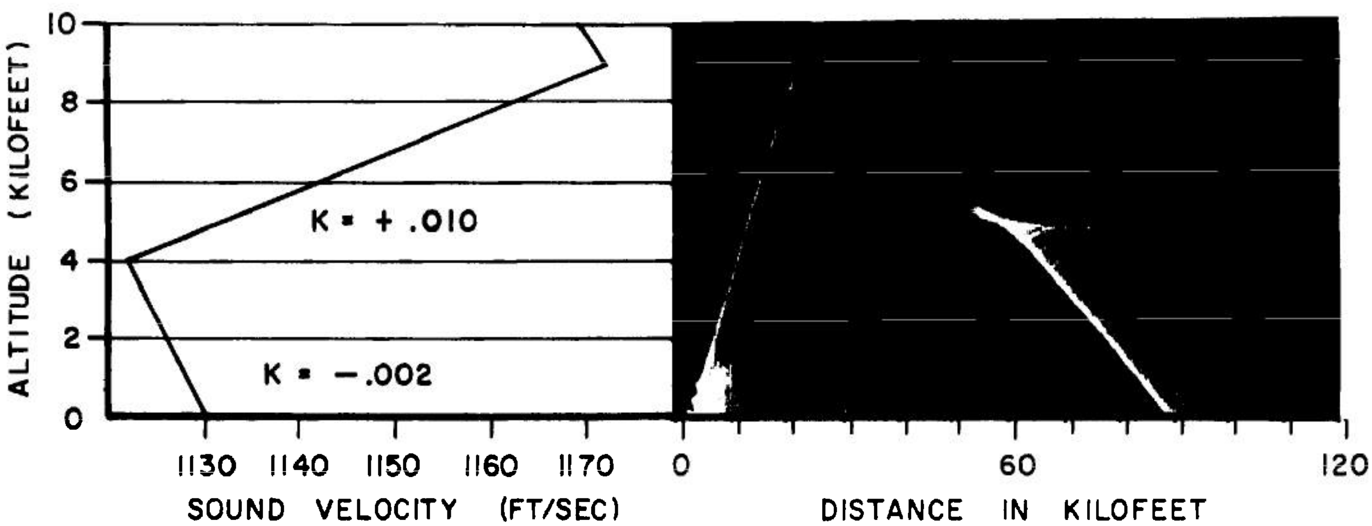

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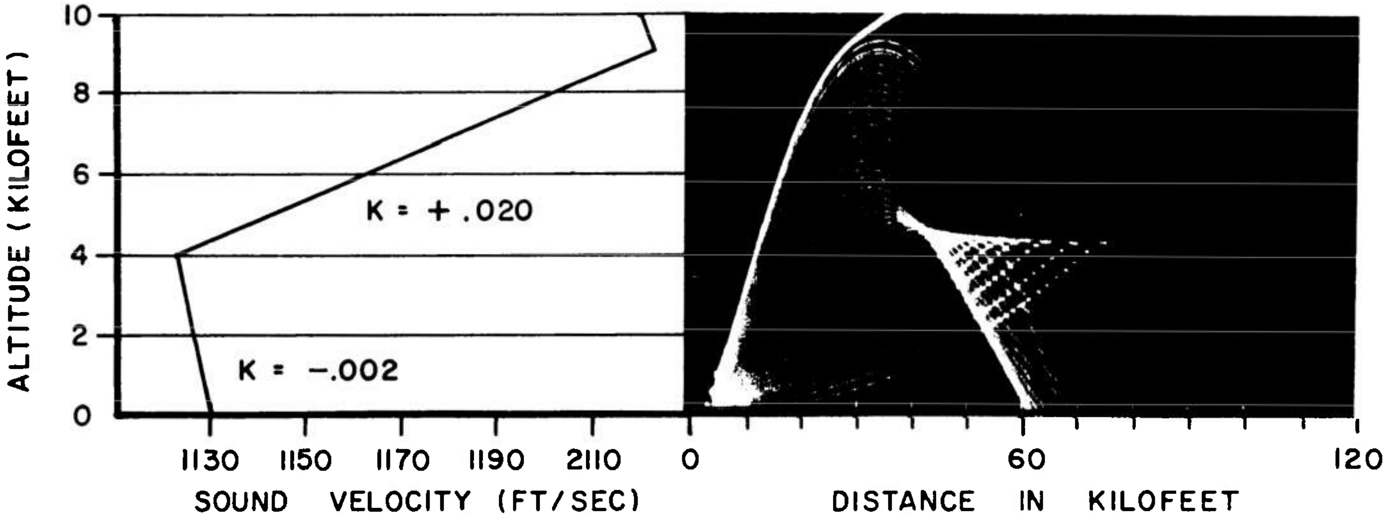

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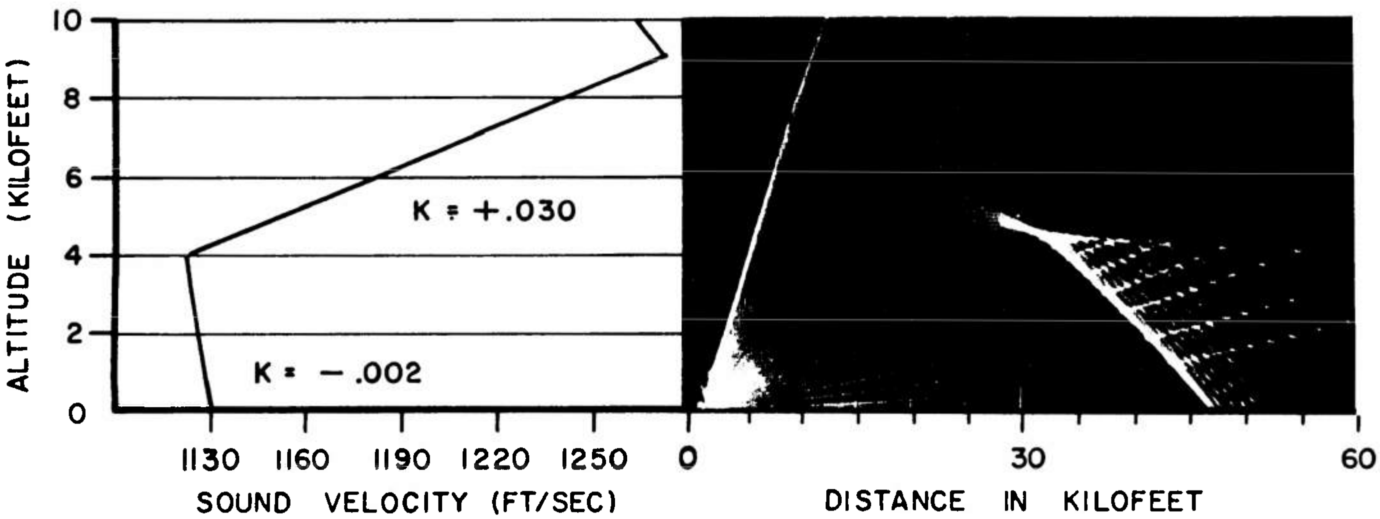

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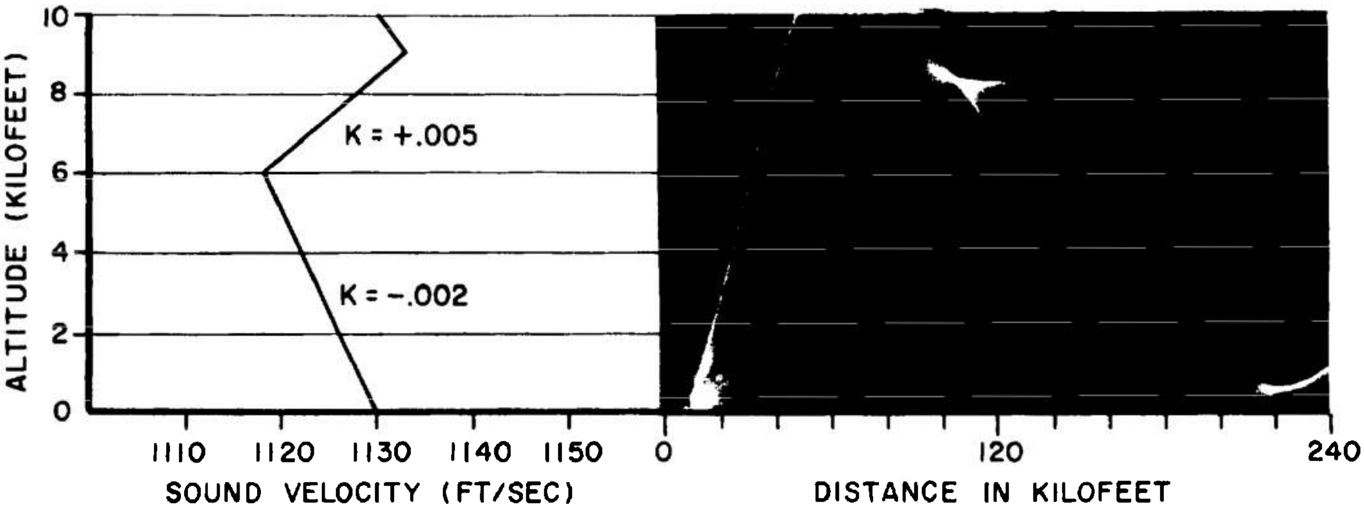

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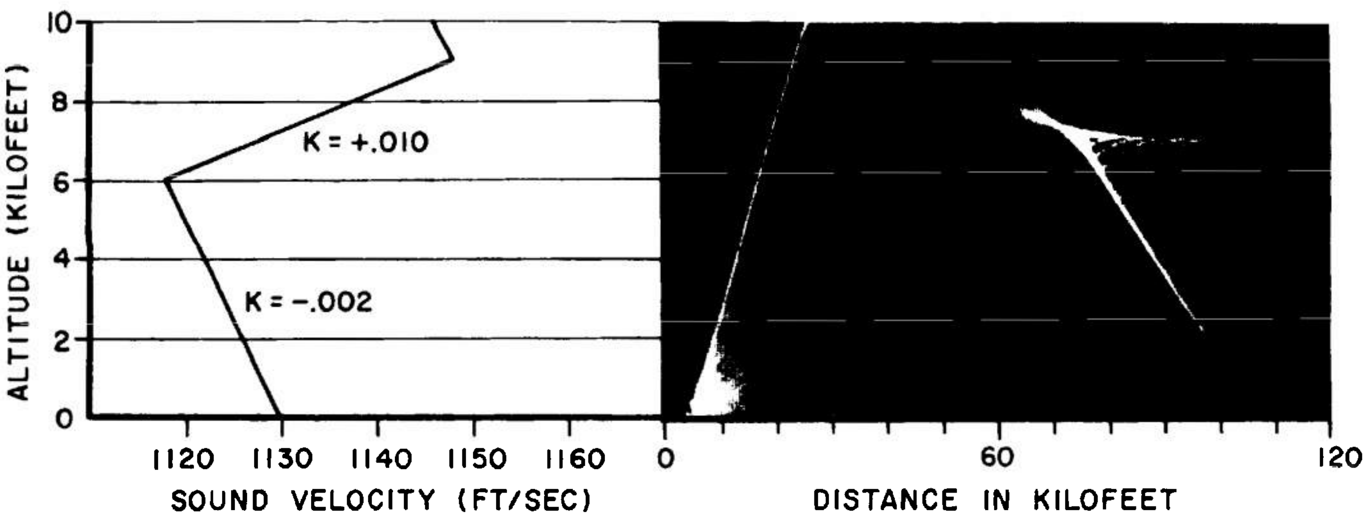

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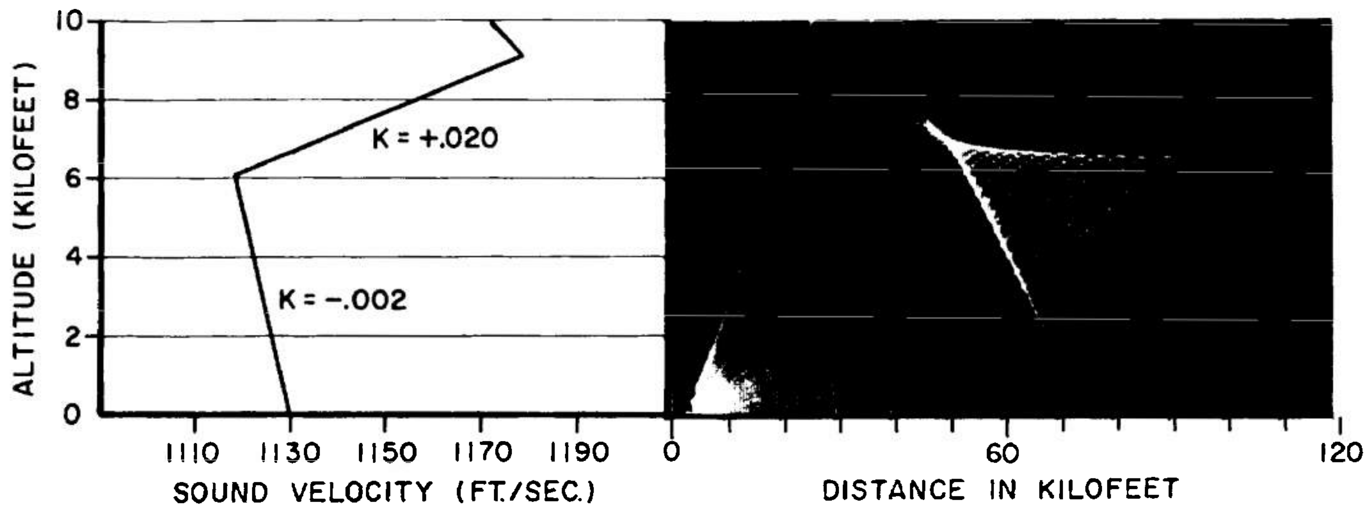

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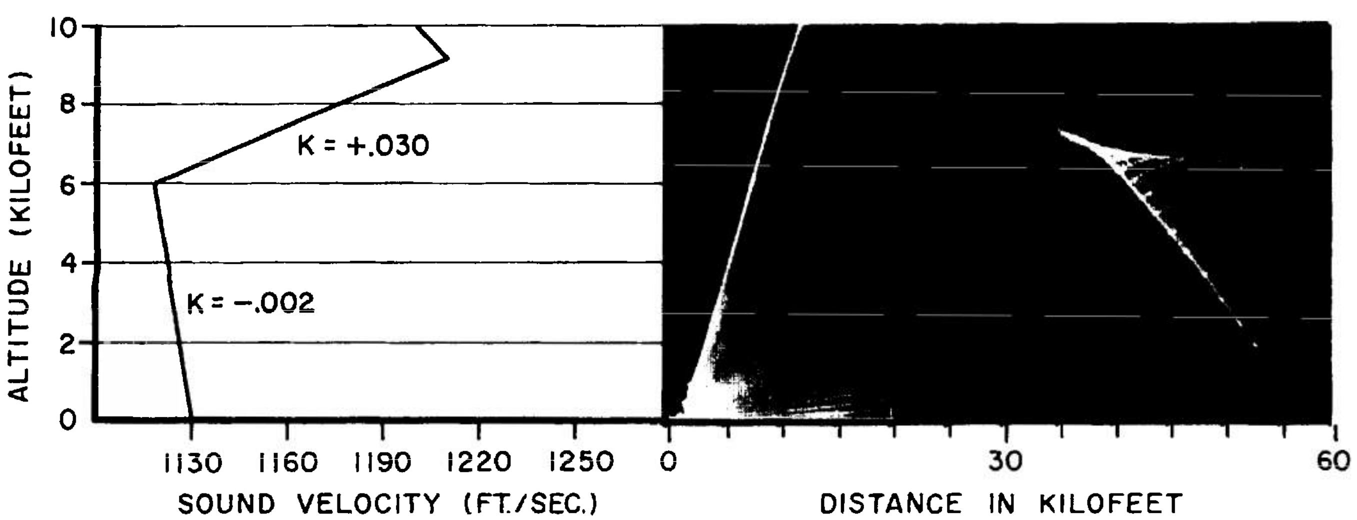

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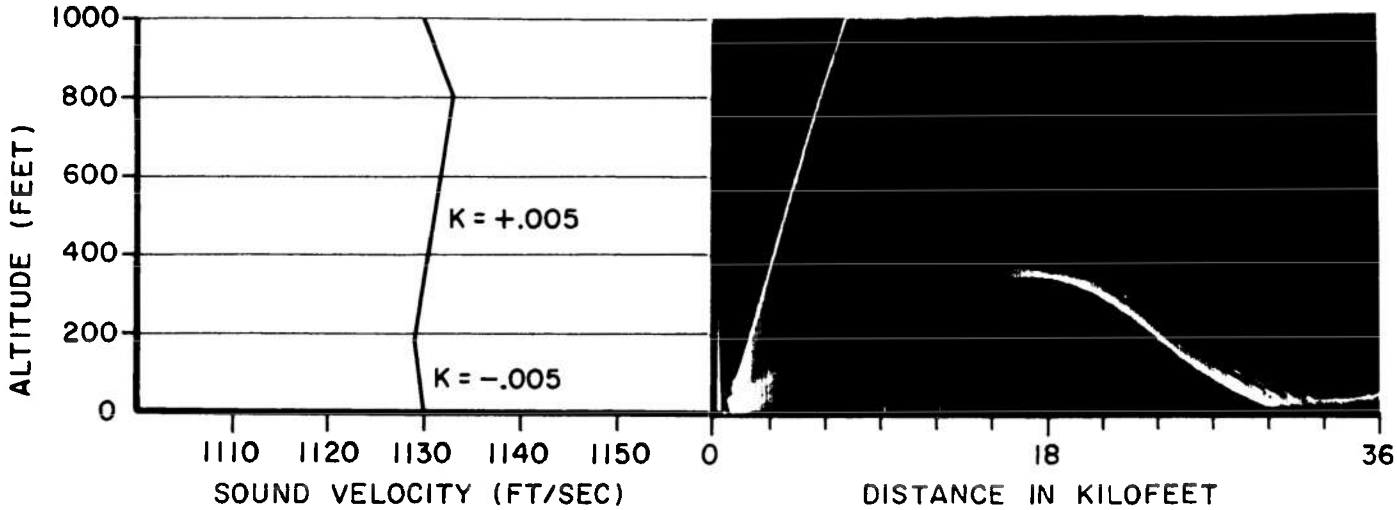

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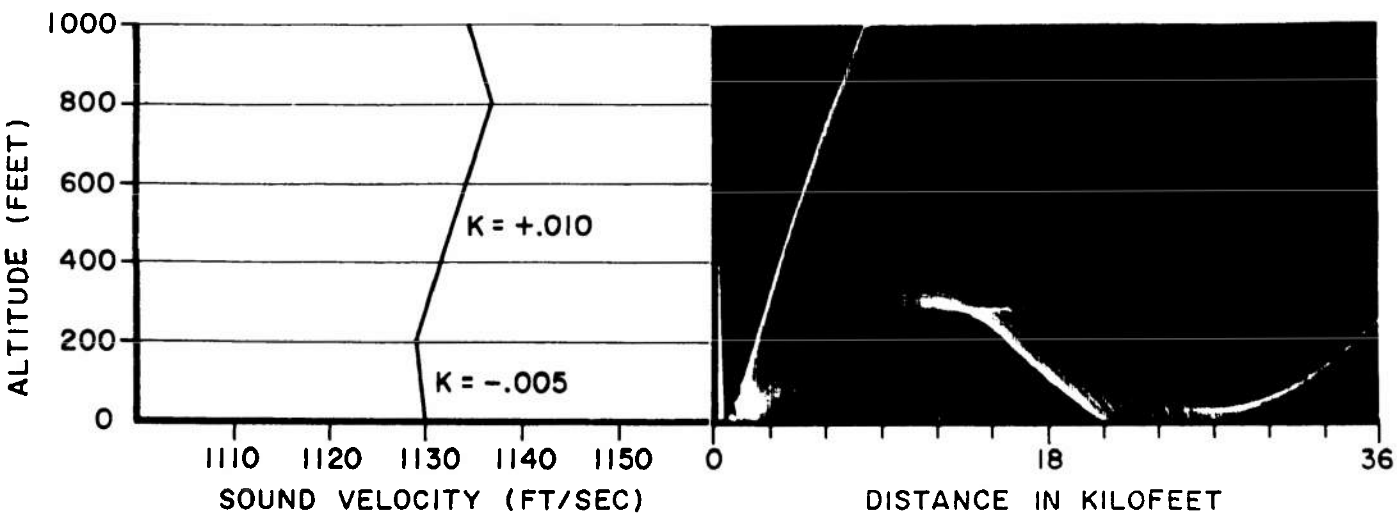

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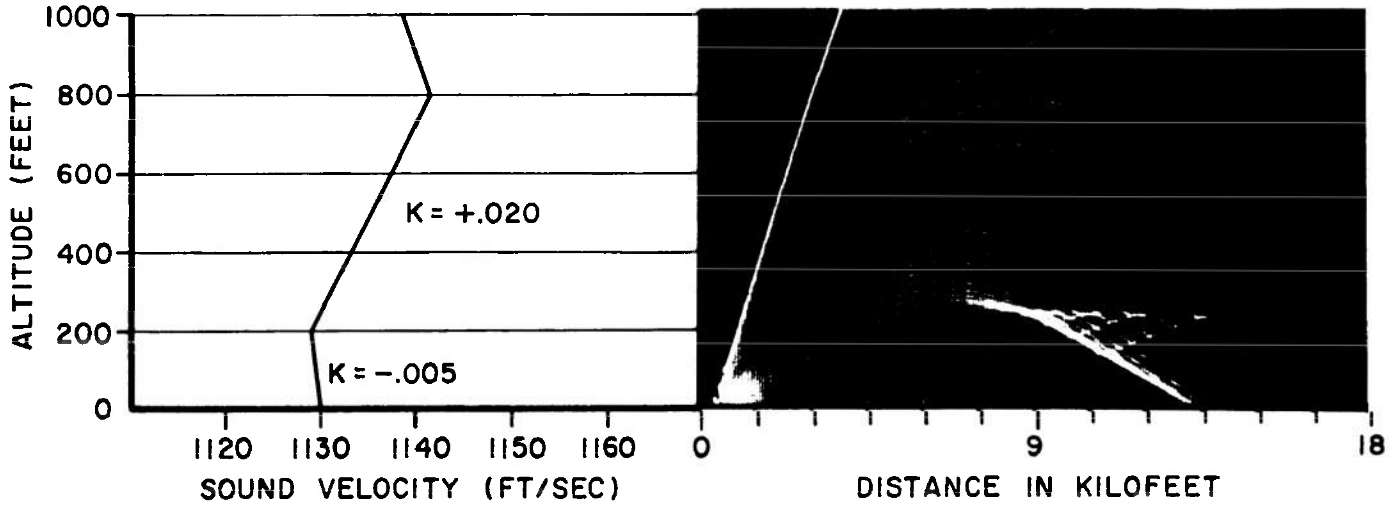

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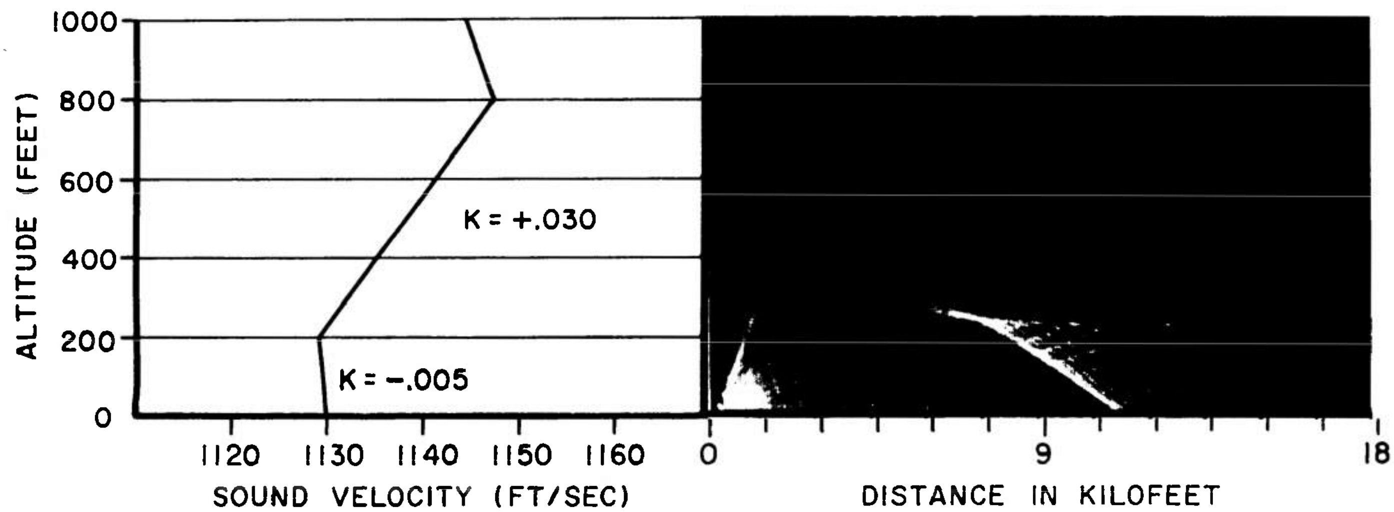

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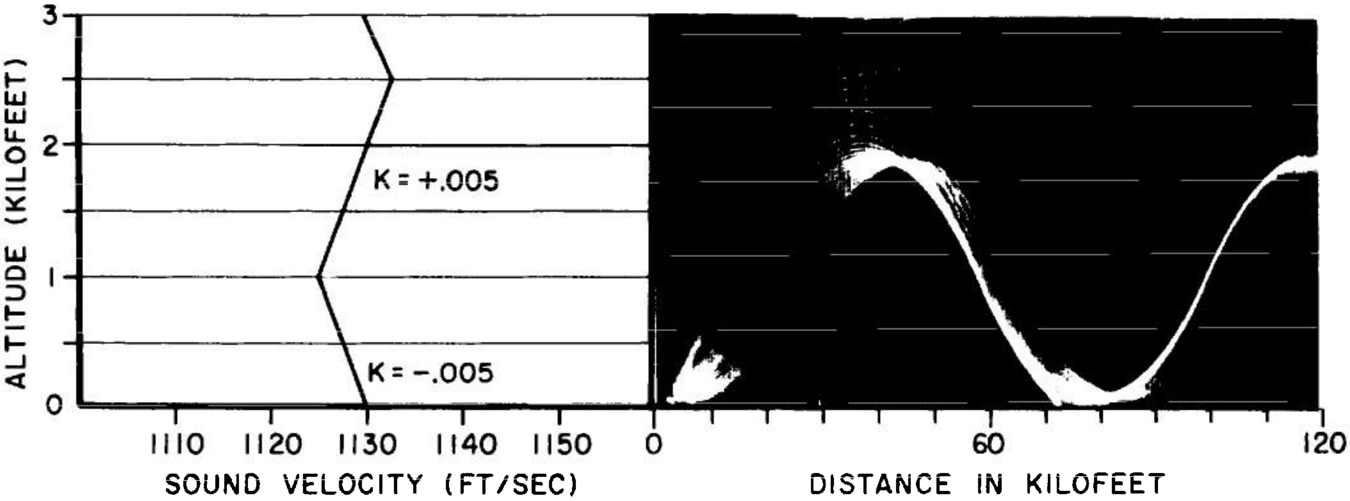

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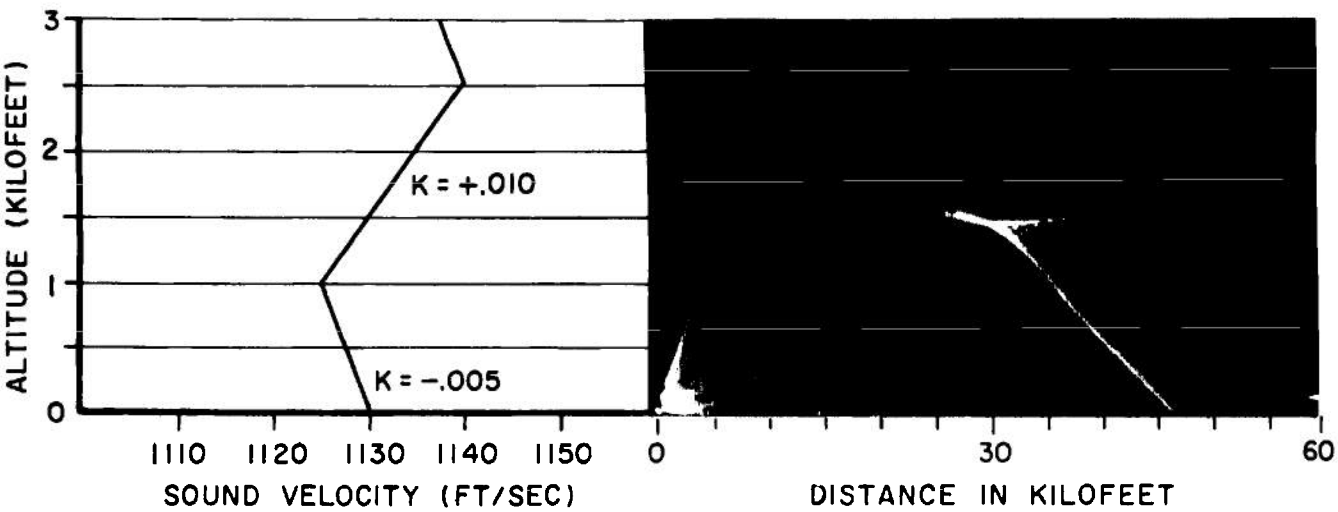

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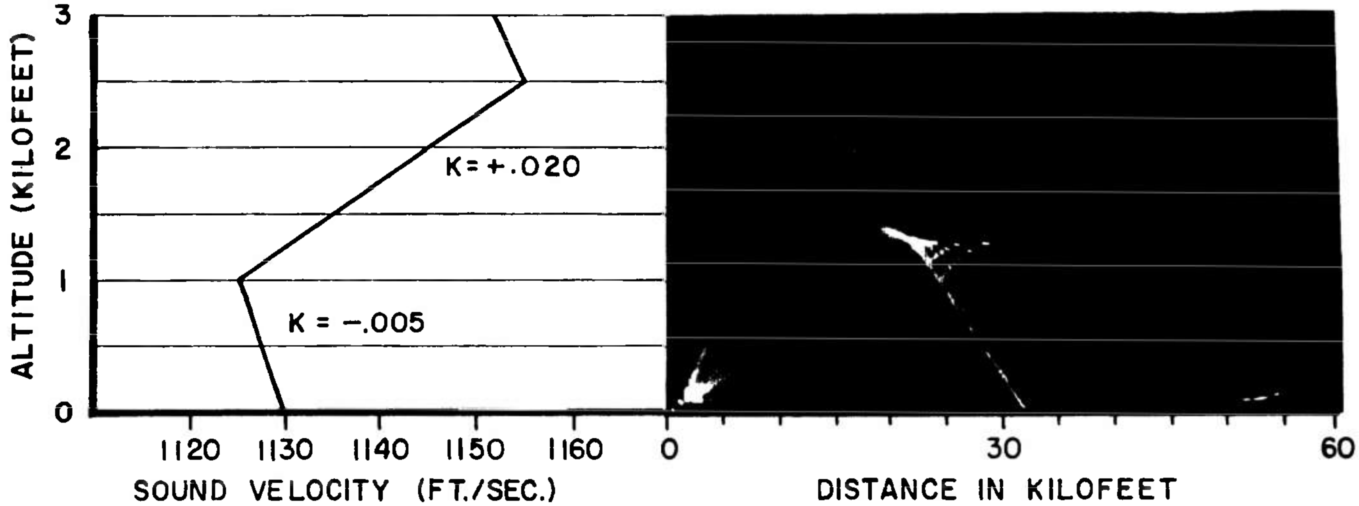

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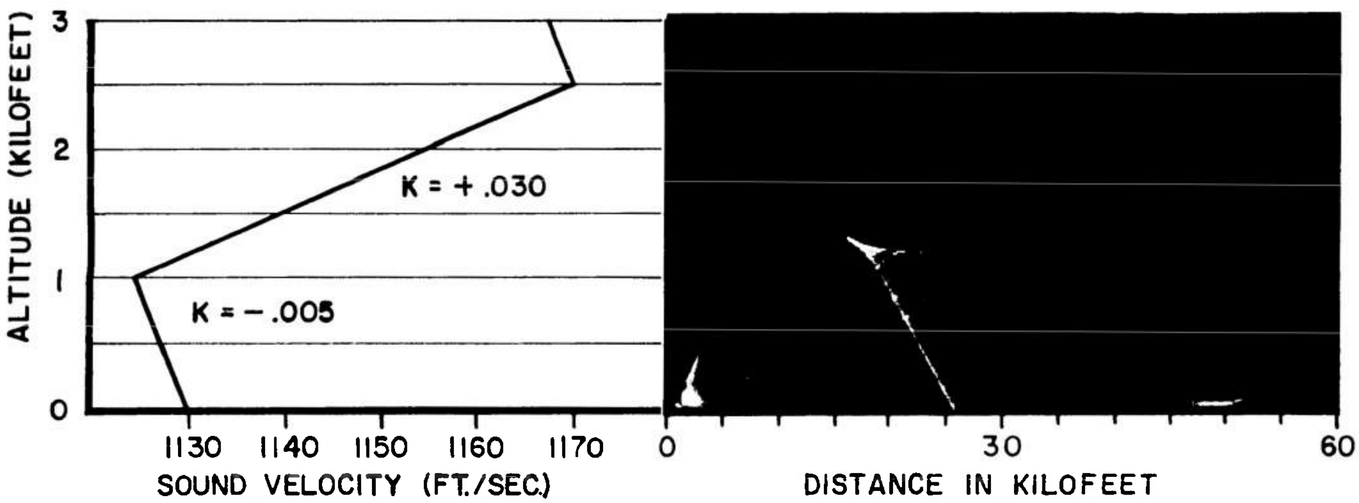

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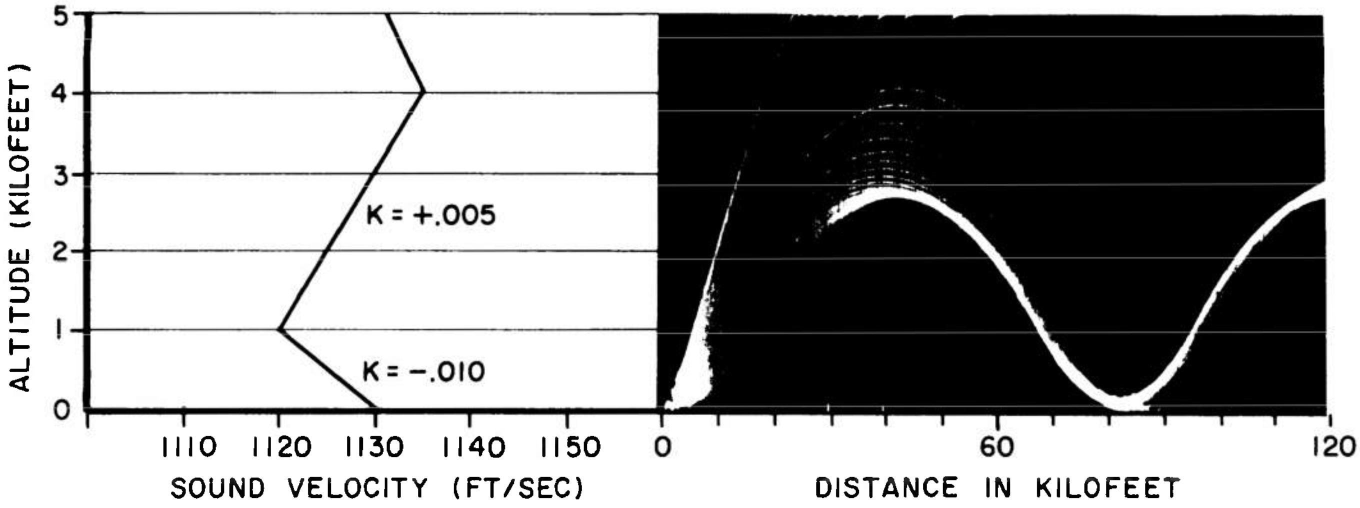

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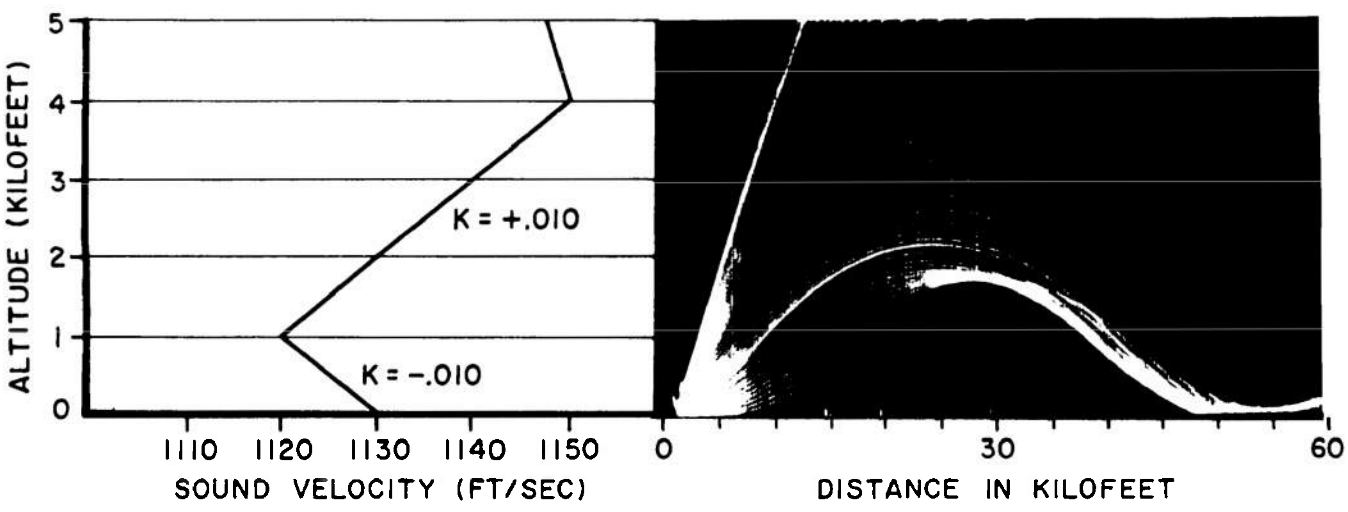

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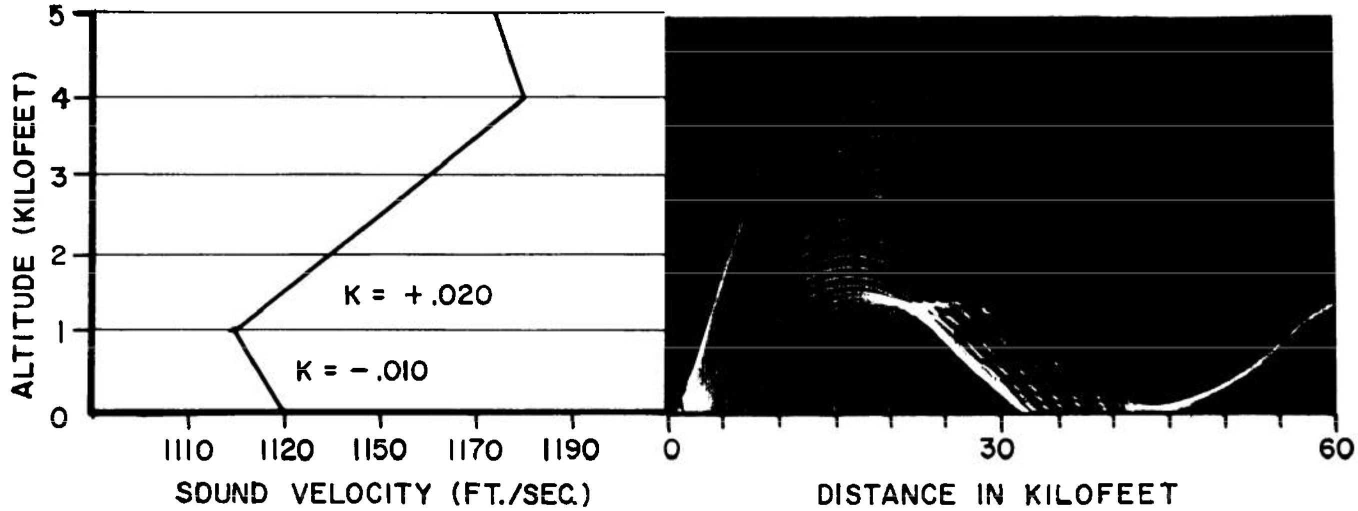

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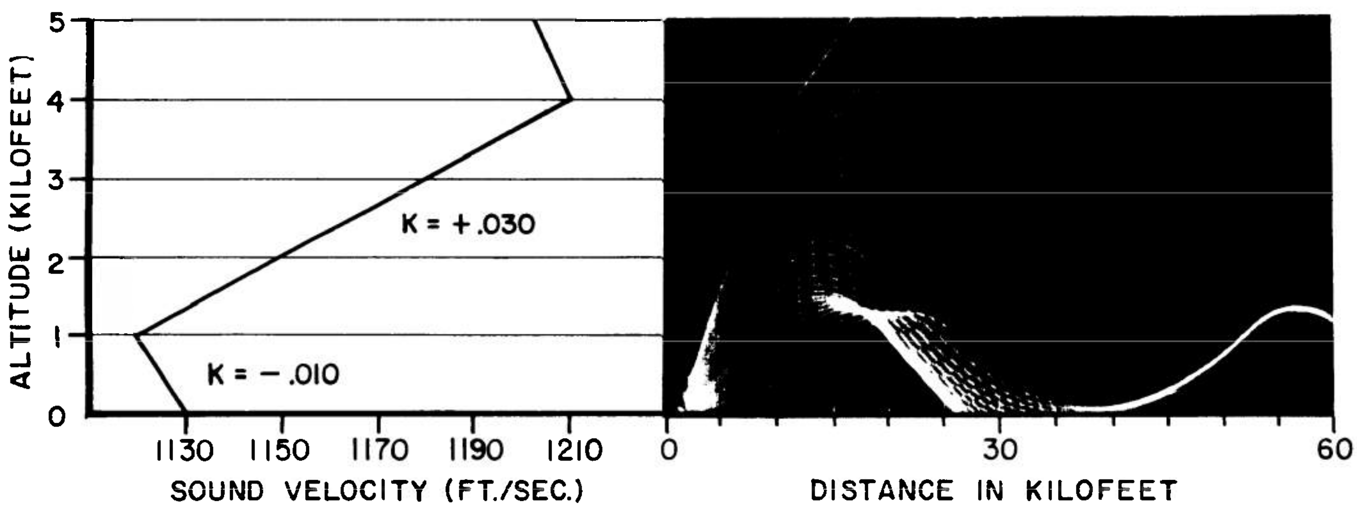

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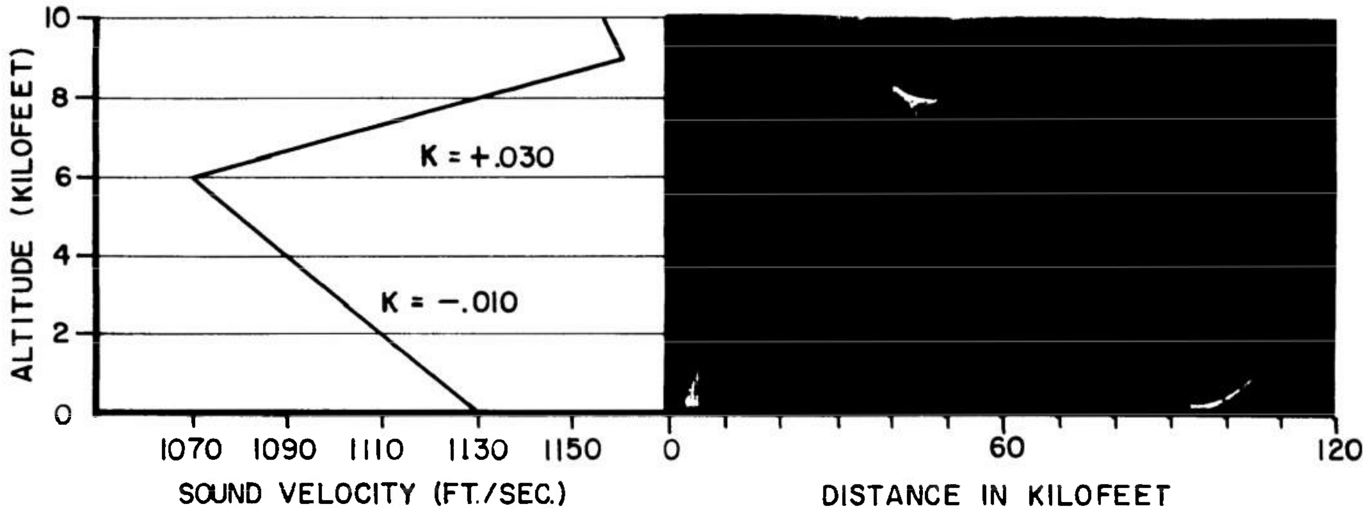

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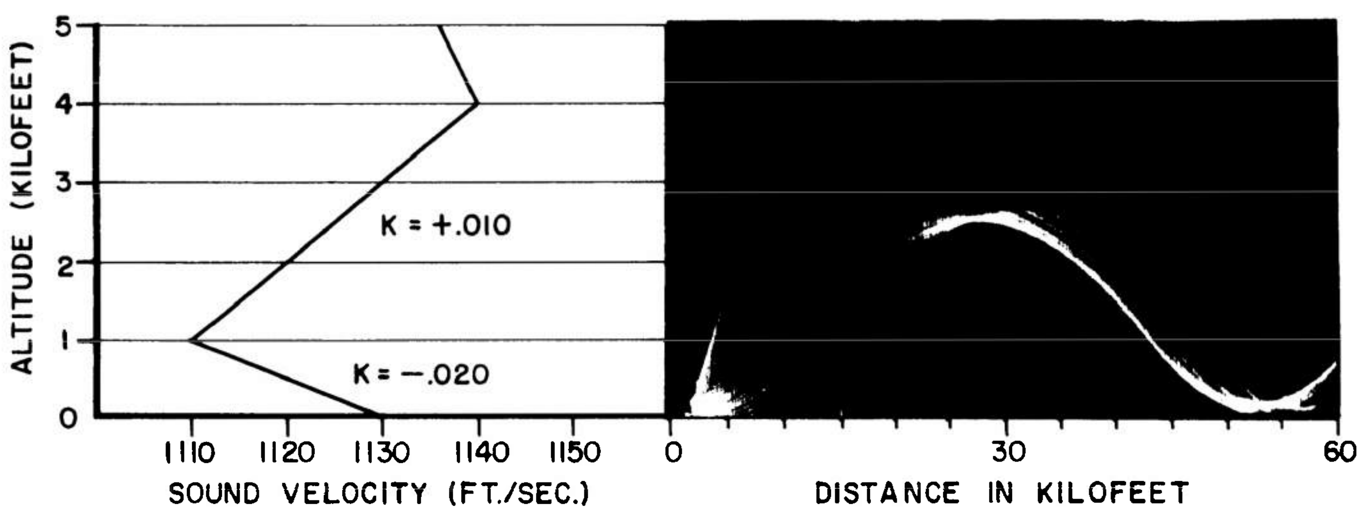

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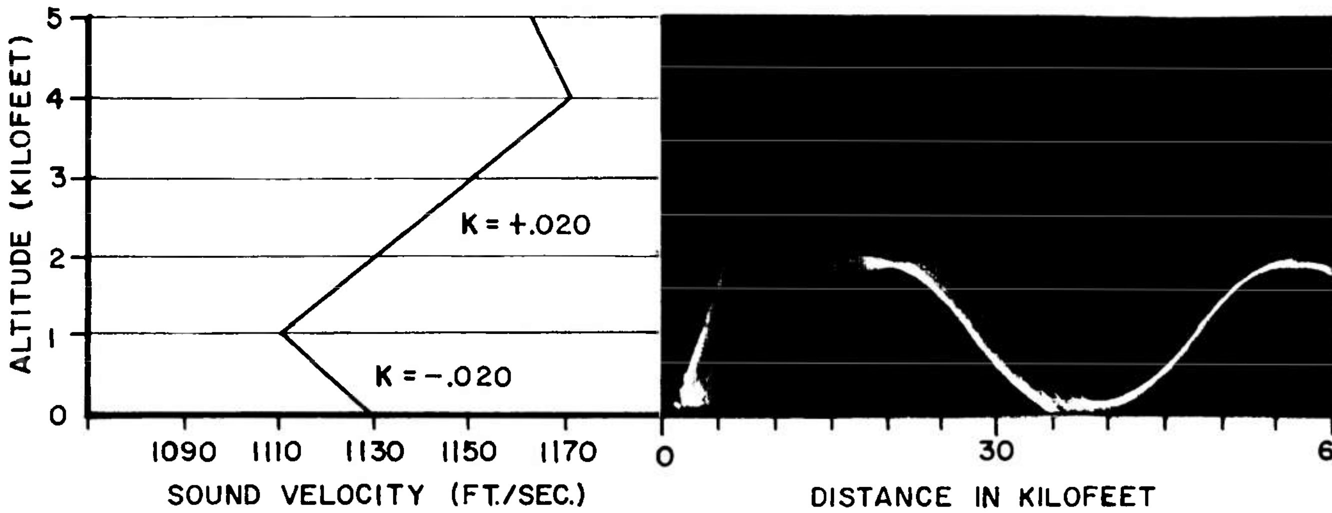

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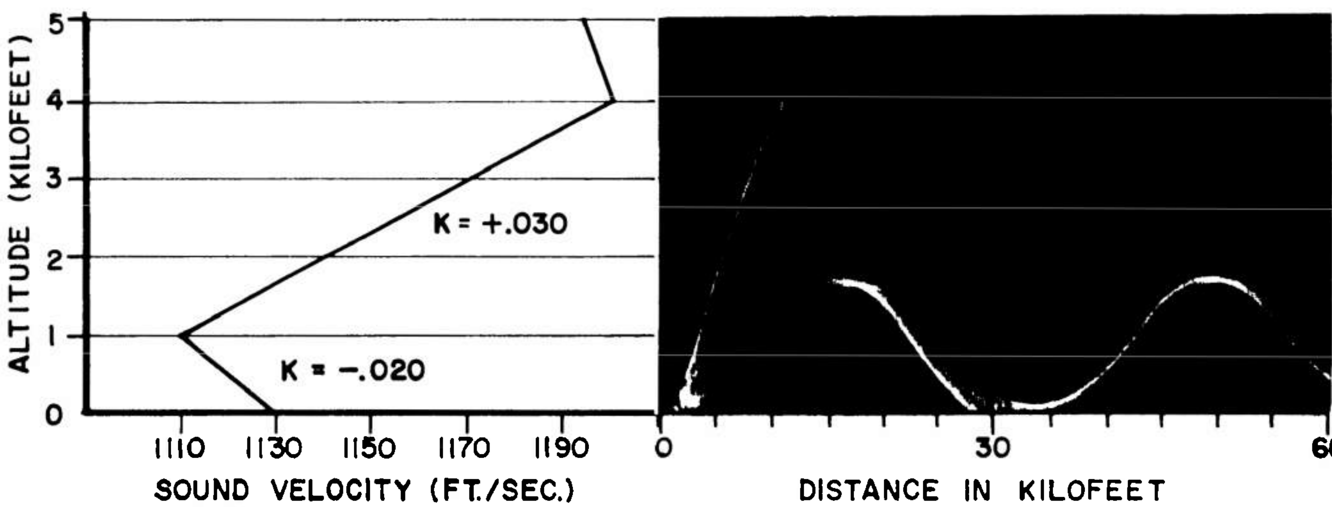

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